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Technical Paper 247

Petroleum Technology 55

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

PERFORATED CASING AND SCREEN PIPE IN OIL WELLS

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no. 247
ENGINEERING

BY

E. W. WAGY

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First edition. April, 1920.

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PERFORATED CASING AND SCREEN PIPE IN OIL WELLS.

By E. W. Wagy.

INTRODUCTION.

One of the essential methods for obtaining production from sandy or cavey oil-bearing formations, such as occur in certain oil fields, is by inserting a string of casing, commonly termed the "oil string," through the producing zones. The ideal condition, for getting maximum production, is an open hole in which the formations "stand up" and the oil moves into the hole, or hub, from the surrounding reservoir without any artificial barrier to its passage. Where the producing formations tend to run or cave such a desirable condition is not possible, and the well has to be finished with an oil string, the parts of the oil string opposite producing formations being perforated so that the oil can move into the well while the loose formations are held in place.

The Bureau of Mines, in its investigations aimed to prevent waste and improve production in oil fields, has made a study of methods of using perforated casing and screen pipe in wells.

This paper describes the various methods of applying the perforation principle, and discusses their advantages and disadvantages. The kinds of casing used can be grouped under the two principal heads of perforated casing and screen casing. A much more important classification, as regards economy and efficiency in subsequent operations, is the methods of making perforations. These also fall into two groups, as to whether the perforating is done before or after the casing is in place. There is a considerable advantage, in known factors, in perforating casing in the shop before placing it in the well, as compared with running the casing into the well and then perforating it. In many instances, however, it is not possible to do otherwise than perforate the casing after it is run into the well, but, in doing so, a number of uncertainties permit more opportunity for an unsatisfactory job.

Obviously, after thousands of dollars have been expended in drilling a well, the perforating should not be turned over to a crew who do not have adequate tools or measurements for the purpose, or to some contractor bent upon speed rather than care. The importance of this statement can not be overemphasized, and, in the discussion

of methods and illustrations that follows, an effort has been made to bring out this fact.

ACKNOWLEDGMENTS.

In preparing this paper, the author wishes to acknowledge the kindly assistance and cooperation given by the following: Messrs. M. E. Lombardi and Wallace Canfield, of the Southern Pacific fuel oil department of California; Mr. R. E. Collom, of San Francisco; Messrs. O. F. Layne, L. F. Basch, Fred Marsh, and W. S. Rae, of Los Angeles, Calif.; Messrs. J. J. Hern, E. W. Bailey, P. A. Williams, and B. F. Parsons, of Taft, Calif.; Messrs. Claud Pearson, Henry Craft and John Pickle, of McKittrick, Calif.; Mr. J. J. Brinkman, of Bakersfield, Calif.; Mr. Paul Paine, of Tulsa, Okla.; Messrs. J. H. McEvoy, C. N. Scott and J. H. Tucker, of Houston, Tex.; Messrs. C. N. Bennett, J. F. Palmer, R. O. Roy, J. Y. Snyder, of Shreveport, La.; and Messrs. B. A. Hare and C. G. Dorn, of Bradford, Pa. The writer is particularly indebted to members of the petroleum division of the Bureau of Mines for many valuable criticisms and suggestions. The illustrative drawings are chiefly the work of J. G. Shumate, of the Bureau of Mines; two were prepared by Lyn R. Schuler. The list of patents and the selected bibliography were furnished by Miss E. H. Burroughs. For clerical assistance, the author is indebted to Miss H. M. Lansche.

DEFINITIONS OF TERMS.

In order to clarify the meaning of the text, as well as to avoid confusion that might arise from the use of local terms, a brief explanation is given of the following terms and words used in this report:

An "adapter" is a tool used to connect a smaller size of casing to a larger size. It is used when several strings of casing have been inserted in the same well and the inside string has been cut off below the top of the hole. The adapter is set on top of the inside casing to keep it from getting damaged, and also serves as a guide when a bailer or tubing is run into the well.

The "band wheel" is part of the equipment of a standard drilling rig; it is a large pulley 9 to 16 feet in diameter, made suitable to carry a flat belt 10 to 12 inches wide. By means of this belt the power from the engine is imparted to the band wheel.

The term "bean" (often called flow nipple), is applied to a nipple used for restricting the flow of oil from a flowing well. It is a steel nipple whose internal diameter is much smaller than that of pipe of the same external diameter.

"Bull wheels" are part of the equipment of a standard drilling rig. The shaft is 12 to 14 feet long and 16 inches in diameter, and is used as a spool for the drilling line or cable. About a foot from one end of the bull-wheel shaft a rope pulley 7½ or 8 feet in diameter is placed for receiving power from a rope pulley on the band wheel, by means of a rope about 2⅛ inches in diameter. Power is transmitted from the band wheel to pull the tools out of the well. On the opposite end of the bull-wheel shaft is a pulley fitted with a flat brake band about 6 inches wide. This brake is used for controlling the speed of the tools when lowering them in a well, or hold the tools from falling in case of emergencies. (See "band wheel.")

The "calf wheels" are used to handle casing. The wheel itself is 7 to 8 feet in diameter, fastened to one end of a shaft 16 inches in diameter and about 5 feet long. The shaft serves as a spool for the wire line with which the casing is handled. Power is transmitted from the band wheel to the calf wheel by means of a wire or manila rope; also a chain is used. (See "band wheel.")

A "casing shoe" is a cylindrical piece of steel turned in a lathe, and is made to fit any size of casing desired. The shoe is screwed onto the bottom joint of a string of casing to strengthen this joint and to help cut the hole when light strings of casing are used so that the pipe couplings will pass through easily.

The term "clamps," as used herein, refers to heavy irons made to conform with the shape of the casing, and bolted around it under a coupling for the purpose of taking some of the weight off the bottom joints of casing.

"Drilling in" refers to drilling into the producing oil zones, and is usually the final drilling work done in completing a well.

"Elevators" are used for handling casing, and are placed just under a coupling. They have a hinge joint, and are so shaped that they fit the casing snugly but will not slip over the coupling. Link attachments are provided in which a hook is placed when working with casing or tubing.

"Heaving sand" is a term used by drillers to describe a sand that runs in and fills a hole some distance from the bottom. It may be carried up the well by water pressure or gas pressure, or both.

"Jars" are linked tools used in standard drilling practice for keeping the bit free when drilling in sticky material and in fishing out lost tools.

The "jerk line" is a piece of wire or manila rope 20 to 26 feet long, used to give the required motion to the tools used in standard drilling practice, whenever use of the walking beam is impractical or undesirable. (See "spudding in.")

The "lead line" (or flow line) is the pipe line that conducts the oil and gas from the top of the well to a settling or gage tank.

"Liner" is a short string of casing, usually extending from the bottom of the hole to a short distance above the shoe of the next larger size casing, for the purpose of holding up the walls of the hole. It is usually some form of screen or shop-perforated pipe.

A "lug" is any projection that is fastened onto a larger body.

"Mandrel," as used in the text, refers to a round piece of steel of any length and diameter working through a hole drilled in a larger body of steel; in other words, one of the working parts of a perforator.

An "oil string" is the casing that is placed in a well through the producing oil sands to keep them from caving. The bottom joints of such a string of casing, or those sections that are opposite the producing oil sands, are some form of perforated casing. Perforating is necessary to permit the fluid to run into the hole where the pump can raise it to the surface. The term "oil string" is used in contradistinction to the term "water string," which is the casing that is placed in an oil well to exclude water from the well.

"Parted job" refers to the work that results when the tubing used in perforating is parted, or pulled in two. The upper part of the tubing is pulled out and run back in with a suitable fishing tool on the bottom so as to fish out the remainder of the tubing.

The "pitman" is the connecting rod between the wrist pin on the crank of the band-wheel shaft, and the walking beam. As the crank of the band-wheel shaft turns, the pitman imparts the reciprocating motion to the walking beam, which raises and lowers the tools in the well. (See "band wheel.")

"Redrilling" is necessary after an oil string has reached such a condition that a bailer or pump can not reach bottom, or when water has broken in around the casing. It often involves the operations necessary to side-track or recover the old pipe and to replace it with new pipe.

"Sanded up" means that the working parts of the pump have become so clogged up with sand that it can not be operated. The term is also applied to a well where so much sand has run into the hole that production is either retarded or completely shut off.

"Screen pipe or casing" is a patented variation based on the perforation principle, for preventing sand from running into a well. There are two general types—the button and the wire wrapped.

"Sealing iron or tool" is a tool used to swage out a lead seal ring used for an adapter to make it conform with the diameter of the outside casing.

The term "shot," as used herein, refers to the practice of setting off a charge of some explosive in a well. This is done to shatter

compact sands or limestones for the purpose of increasing the flow of oil into the well, to break up old casing tools or other obstructions that may be in the well, to loosen casing, etc.

A "shoulder" is the ledge or projection of a formation on which a string of casing is usually set when it is finally landed.

The term "spudding in" refers to the method of starting the first few feet of hole in drilling a well with standard tools. It is in this work that the "jerk line" is used, by placing one end on the "wrist pin" and the other end on the drilling line above the "bull-wheel" shaft. As the crank on the band-wheel shaft turns, the tools are raised and lowered. (See "jerk line.")

"Stands" refer to the sections of pipe that are stood in the derrick when a well is pulled. The length of the "stand" depends on the height of the derrick. It is usually composed of three joints of pipe, and is about 60 feet long.

"Strainer pipe" and "screen pipe" are used synonymously.

A "string of casing" is a number of joints of casing which are placed in a well. A joint is about 20 feet long.

"Swabbing" is one of the operations used in attempting to increase the flow of oil into a well. It consists in placing a swab on the tubing or tools and running the swab up and down as fast as permissible within the perforated pipe. The swab is made to fit the casing tightly enough so that no fluid can pass between it and the casing, hence the fluid is forced out through the perforations and is supposed to assist in washing the finer sands into the well. A swab may be 8 to 24 inches long.

A "swage nipple" is a reducing nipple, for connecting a larger size of pipe to a smaller, or vice versa.

The term "tools" refers to the regular equipment used in standard drilling practices; it includes a rope socket, a set of jars, a stem, and a bit. Occasions arise where other tools are necessary, as in fishing, perforating, and other special work.

The term "tubing," as used in the text, refers to the pipe through which the fluid is pumped, or flows, to the surface.

A "tubing hook" is an ordinary iron hook used in handling tubing. (See "elevators.")

The "walking beam," as the term implies, is a large beam of wood about 26 feet long. It is balanced in the middle and the reciprocating movement given it by the wrist pin and pitman raises and lowers the tools in the well. (See "wrist pin" and "pitman.")

The "wrist pin" is the pin used in the crank on the band-wheel shaft, on which the pitman is placed to give the reciprocating movement to the walking beam when drilling.

FAULTY PERFORATING.

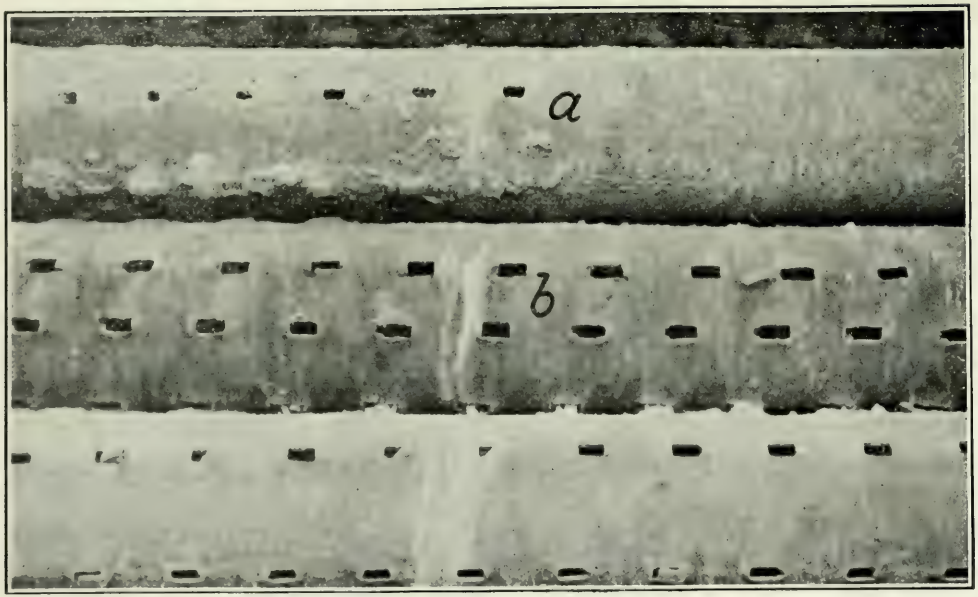
CAUSES AND RESULTS.

In numerous perforating jobs the casing has been so badly damaged by careless or faulty perforating that it was necessary to redrill the well. Either the pipe was so weakened as to cause complete collapse, or else so much sand came through the perforations that the well could not be operated economically. The accompanying photographs show pipe in which the holes were all punched on one side (Pl. I, *A* and *B*) and, in certain pipe, nearly all run together (Pl. II, *A* and *B*). Good results can not be expected from such conditions. At some wells pipe supposed to have been carefully perforated has been pulled out of the well, and the holes were found only partly cut, or the casing merely dented. (See Pl. III *A*, p. 10.) This condition often results from the fact that the perforator, before being lowered into the well, is not tested in a sample joint of casing.

In some casing the holes were not properly punched, even where the perforator was tried in a sample casing above ground and found to be working properly; perhaps because the casing in the well was of slightly larger diameter than the test joint or else was of tougher material. Some pipe has been seen where the perforating machine failed to punch a clean hole. Therefore it is necessary that the same kind of pipe as that used in the well should be tried for a sample perforation. In practice, however, sometimes a nipple or "pup joint" of casing picked up at random is used, and dependable results are not obtained.

Although the perforator can be adjusted to insure cutting holes in a mixed string of pipe, the knife may punch through too far. When this happens to a machine with inserted teeth they will be pulled out, unless they are rounded off on the top edge. Other machines, where the knife is all one piece, will draw in a part of the casing shell at the top of the perforation (Pl. III, *B*), leaving a ragged uneven surface on the inside. This leads to difficulties in cleaning and swabbing the well.

As the wear and tear on a perforating machine is usually very great, completing the job successfully without pulling the perforator up for repairs is sometimes a difficult matter. Often work is continued even after it is obvious that good results are not being obtained. It is therefore very important that someone thoroughly responsible and experienced with the working of the perforator be present while this work is being done. Also, all the cutting should be done at one time. If at any time reperforating is necessary, it is almost certain that the knife of the machine will enter some of the old perforations and enlarge them, or, by coming too near others, will cause local fracturing and tearing (see Pl. II, *A* and *B*),

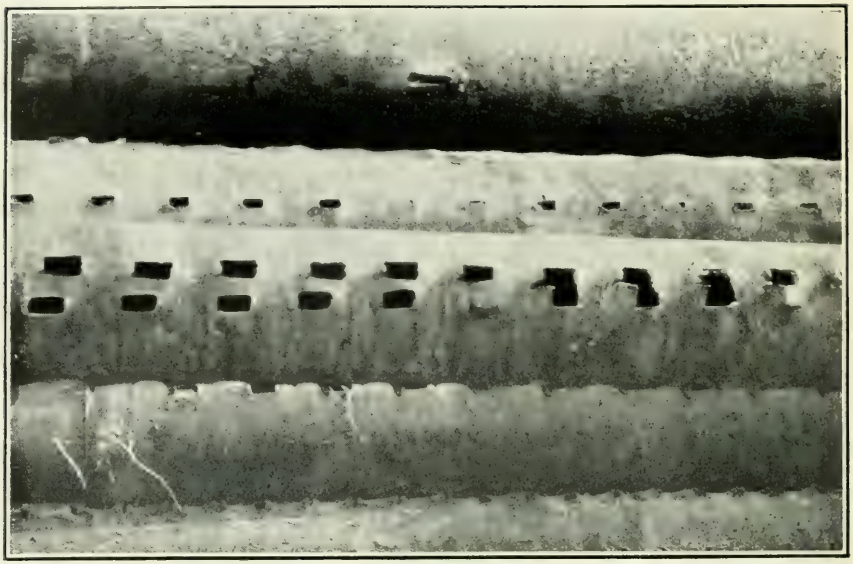


A. CASING PERFORATED IN THE WELL.

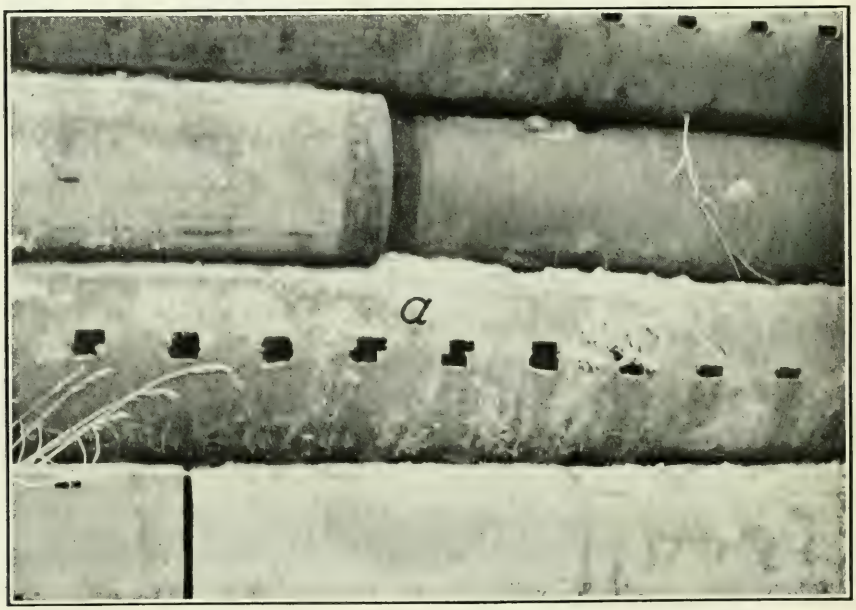
a, Shows lower row of holes only partly cut out; *b*, shows poor arrangement of holes, all being on one side of the casing.

B. CASING PERFORATED IN THE WELL.

Perforated too near the end of the joint; also all holes are on one side of the casing.



A. CASING THAT HAS BEEN REPERFORATED IN THE WELL. SOME OF THE HOLES ARE RUN TOGETHER, CAUSING ENLARGED AND VERY ROUGH OPENINGS.



B. CASING THAT HAS BEEN REPERFORATED IN THE WELL.

a, Holes run together.

thus permitting more sand to come in than can be handled, and also so weakening the pipe that it may ultimately collapse.

Among the early types of perforators the device used for setting the knife was often uncertain in its operation. Because of this fact a machine when being lowered into a well would sometimes trip accidentally and throw the weight of the tools on the knife, causing a hole to be cut at an undesirable place in the casing. Accidents of this kind are not so prevalent now. The mechanical operation of these machines has been improved so that they are under more complete control, and the casing used in most wells is heavy enough to withstand the weight of the tools on the knife without being cut.

METHODS OF PERFORATING IN THE WELL.

Two methods of perforating casing in the well are in common practice—in one method the tools are used as with a drilling line; in the other, the tools are placed on a string of tubing.

Each of these two methods of perforating has its advantages. The work can be done quicker with a drilling line than with tubing. On the other hand, with tubing there is the advantage of being able to direct the position of the holes in the casing. With many types of machines this is necessary. A single-knife machine can not be properly run on a drilling line. However, in perforating work, tubing sometimes undergoes severe strain or shock, caused by the weight of the tools and of the tubing itself, and also by the intense vibration. Hence, "parted jobs," caused by failure of the tubing or by turned or stripped threads, are common experience.

PRECAUTIONS IN PERFORATING A WELL.

When running the perforator on a drilling line, often difficulty is caused by using too long a stroke in driving down with tools swinging from the beam. The driller may think he has plenty of latitude because of having on a set of 36 or 42 inch stroke jars, whereas if the wrist pin has not been moved from the usual drilling hole in the crank, or if the motion of the beam is not slowed down, the machine will more than likely be striking on the up stroke and getting no results. This has often happened, with the result that the machine in use was thought to be out of order, when the fact was that the "spring" of the line caused the tools to swing with a stroke longer than that of the jars in use. As soon as the wrist pin was changed to shorten the stroke, or even in some instances where the motion was retarded, the perforator worked smoothly.

Another important thing to guard against is not to cut too near a coupling (see Pl. I, *B*). Often, after perforating, the casing is

"hung up" on clamps under a slight strain, and, if a hole has been punched at a coupling, the pipe is liable to pull out. Besides, there is danger of the pipe collapsing, because a cylinder under side pressure will give more readily when cut or perforated near the ends. Moreover, should it ever be desired to pull the perforated casing, evidently the chances of doing so would be materially lessened if the casing had been cut at or near the couplings.

For future work on the well, therefore, an accurate casing record is of great service, and much care should be taken to get accurate measurements at the time the work is being done. In order to avoid any errors in measurements, it is best to measure the tools and line, or tubing, whichever is used, when running them into the hole. By checking these measurements with the casing record, the chance of any discrepancies entering into the work is materially lessened. This is very important, in order to know at all times just where the machine is cutting.

It is customary to start at the bottom of the well and perforate the bottom joints first, beginning at the top of each joint and cutting a distance down equal to the length of the joint as taken from the casing record, or cutting from the bottom of the joint up, according to the style of the perforator used. In order to keep the sand from rushing in and interfering with the working of the perforator the hole is kept full of water.

The machines used are largely a matter of personal choice. It is unfortunate, however, that many operators fail to procure the most efficient type available for this important work, but on account of a saving in the initial cost, rig up an improvised perforator, and probably get uncertain or negative results. As a consequence of this practice more money is spent in the long run than it would have cost to rent a workable and up-to-date model.

SINGLE-KNIFE PERFORATORS.

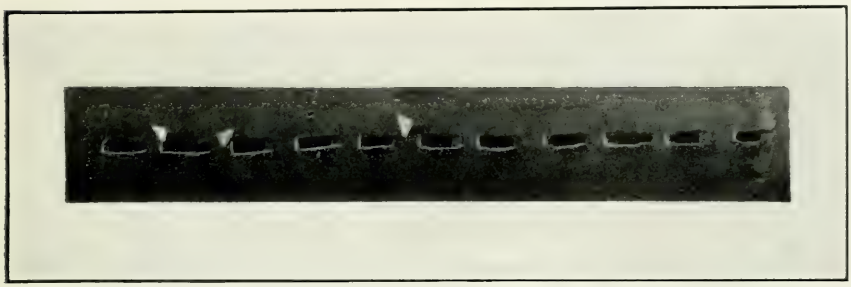
THE "RIPPER."

Of the early types of perforating machines, perhaps the most common was the casing "ripper" or splitter. This machine cut a slit of any length desired. A casing perforated with such a machine is shown at *b*, in Plate III, *C*. In the past it was common practice to make longer holes than is now customary and not so many of them. The ripper is now used more often for ripping off and loosening strings of casing than as a perforator.[a]

[a] Curtain, Thomas, Casing trouble and fishing methods in oil and gas wells: Bull. 182, Bureau of Mines, 1920.

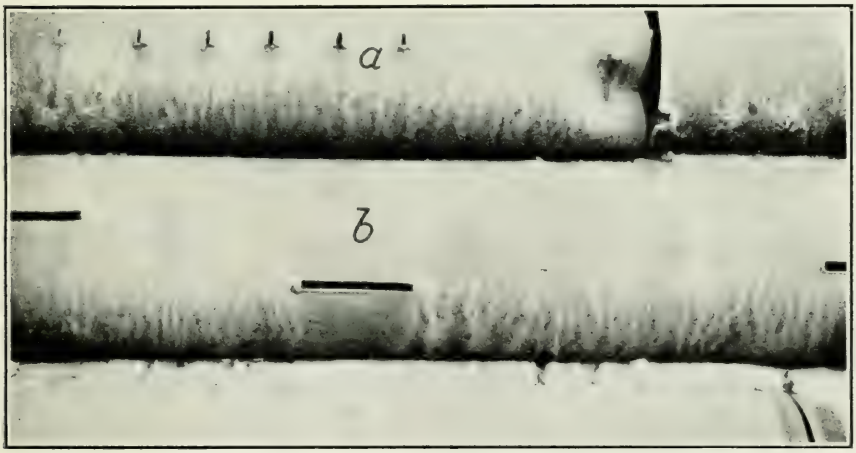
A. CASING PERFORATED IN THE WELL.

Only a few holes were cut; the knife was not constructed to suit the conditions.



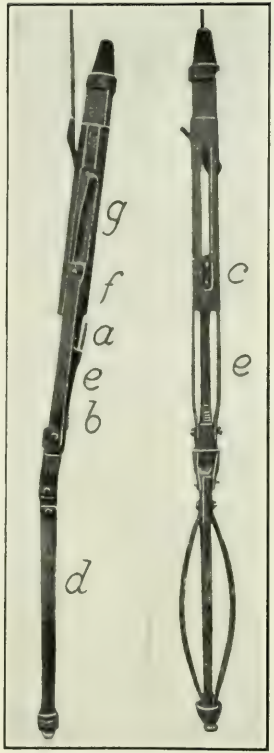
B. CASING PERFORATED IN THE WELL.

Holes too close together and casing is cracked between holes, as indicated by the white markers inserted in the cracks.

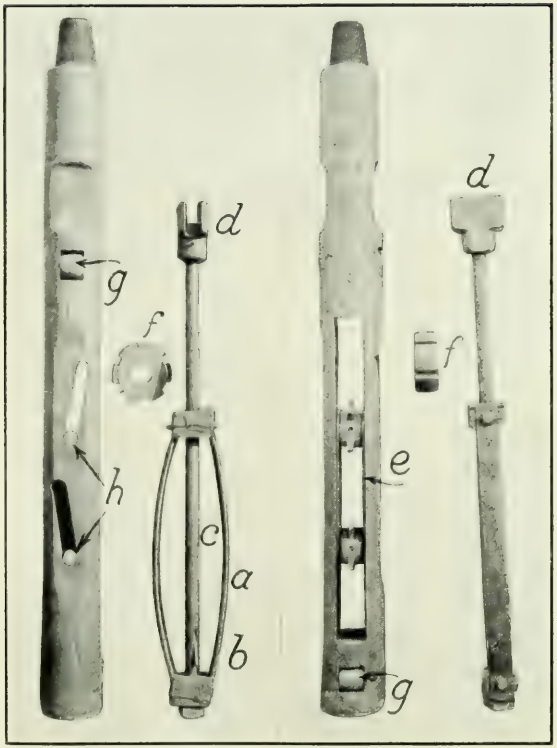


C. CASING PERFORATED IN WELL.

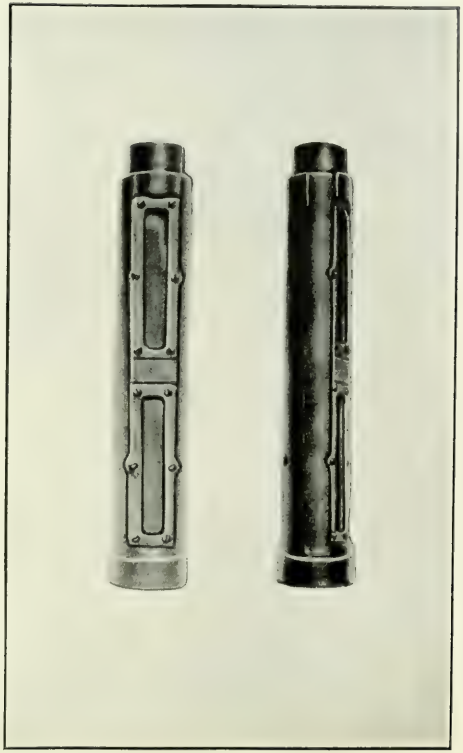
a, Opening made with chisel-edged knife; *b*, results produced by a ripper.



A. HARDISON 4½-INCH PERFORATOR.



B. MACK 6¼-INCH PERFORATOR.



C. HARE OIL-WELL STRAINER.

SINGLE-KNIFE PERFORATOR.

The single-knife perforator (fig. 1) is similar to the ripper in design and construction, and is operated in much the same way. The spring *d* and the mandrel *c* in the bottom set the knife *b*. When perforating with tubing, which is the most satisfactory way of using this machine, on account of the ability to direct the position of the holes, the machine is lowered to the proper place to begin cutting, and then pulled up a short distance. The spring *d*, because of its tight fit in the casing, will drag, so that the mandrel *c* will be pulled up through the spring. The lug *e* will then assume the position shown in the second diagram. When the tools are again lowered, the spring *d* again remains stationary and the mandrel *c* is forced up by the lug *e* and pushes the knife *b* out against the pipe as shown in the third position of the figure. The weight of the tools and the tubing, which in shallow wells is usually filled with water for added weight, or has an extra stem added for this purpose, forces the knife *b* to punch out a rectangular section of the same size as the face of the cutter. When the hole is full of water, it is customary to provide a perforated nipple in the tubing, just above the tools, so that the tubing will easily fill or drain. This is especially desirable in removing tools, in order to avoid a "wet job" as the stands of tubing are unscrewed. If the weight of the tools and tubing combined is not sufficient to operate the knife, the jerk line is put on in the same manner as when used for "spudding-in"; the tools with the jars below the stem drive down the perforator and force the knife through. The tools are then pulled up the required distance for

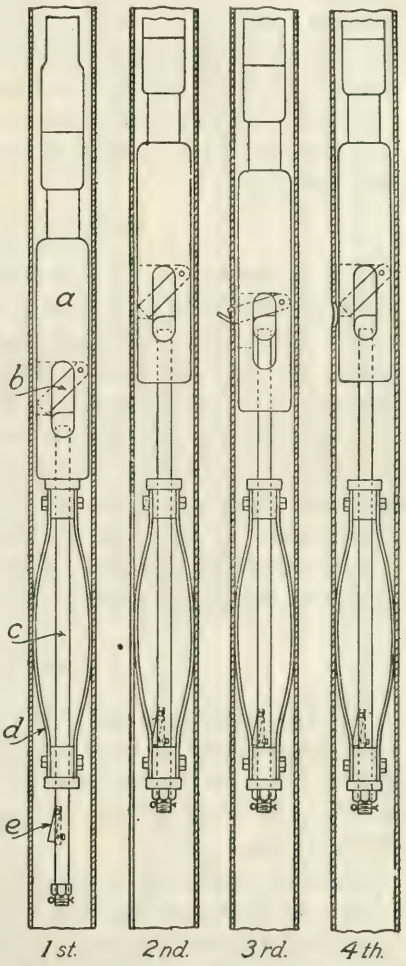


FIGURE 1.—Single-knife perforator. Shows perforator in four different positions, during the procedure of cutting a casing. *a*, Body; *b*, knife; *c*, mandrel; *d*, spring; *e*, lug. Obtained through courtesy of Paul Paine, of Tulsa, Okla.

proper spacing of the holes, and are turned to the right, usually about 90°, when the operation is repeated.

PRECAUTIONS IN USING.

When perforating with this type of machine, one precaution is necessary in order to avoid much loss of time in repair work. The knife should be long enough to rest against the back of the machine; also the pin that holds it in place should have enough play to prevent the force of the blow from coming on the pin. The pin is usually not made heavy enough to withstand the work long, and will soon shear off.

METHOD OF LOOSENING CASING.

If it is desired to rip the casing for the purpose of loosening it, a different shape of knife can be used in this same machine. A knife with a sharp edge, sloping toward the top, is often used. The best results are obtained with a knife having a square face, and so constructed as to turn the cutting it makes outside of the casing. The cutting surface is made a little wider than the rest of the edge in order to keep the knife from binding. The resulting cut will be a wide slot which will permit the casing to collapse slightly. This decreases the diameter of the pipe and allows the sand to run into the well, thereby lessening friction around the pipe. By this method, tight strings of casing have often been pulled.

HARDISON PERFORATOR.

The Hardison perforator (Pl. IV, *A*, p. 11) was one of the first wheel-knife machines to be used in the California oil fields. This perforator cuts one row of holes at a time; it is, therefore, usually run on tubing in order to turn the machine and direct the placing of the rows of holes.

When the machine is being lowered into the well, the knife *c* is so set that it will not touch the casing. As soon as the desired depth is reached, the tools are raised 6 or 8 inches and the spring *d* on the bottom of the perforator, owing to its friction in the casing, will pull a ¾-inch rod, *a*, fitted in the center of the mandrel *e* out of a hole, *f*, in the body of the perforator. The rod *a* will then be forced by a small spring, *b*, or rubber band into a slot cut in the mandrel *e*. The mandrel *e* can then be forced up when the tools are lowered again, which will force the knife *c* up along inclined slots, *g*. These slots, which are cut in the body of the perforator, incline out toward the top, so that the knife *c* will eventually be forced against the pipe, and as the weight of the tools and tubing are added, will punch

through the casing. If the tools are lowered further, the knife rotates and the other points are forced through.

This machine is similar to other wheel-knife perforators, except in the device for setting and tripping the knife. When once tripped, the knife can not be set again without pulling the perforator out of the well.

Where the casing to be perforated is of smaller internal diameter than the casing at the top of the well, the spring and mandrel have to be wired in order to hold a small rod in place, which keeps the mandrel from tripping the knife. When the spring has entered the casing for which it has been adjusted, the wire can be broken easily by turning the tubing slightly.

STAR PERFORATOR.

A favorite machine among many operators is the Star perforator (fig. 2), which is operated on tubing. This also depends on a spring, *a*, and mandrel, *b*, for setting the knife, *c*, which is shaped like a five-pointed star. The knife can be set and tripped at any place desired by pulling the tubing and turning either to the right or to the left. The mandrel *b* has a lug *d* on it which fits in a slot in the side of the perforator, thus preventing the knife *c* from being forced into position for cutting while the apparatus is being lowered in the hole. To set the knife, the tubing is turned to the right, which turns the the lug *d* out of the slot and permits the knife to be forced up in place by the friction of the spring *a* in the casing. A row of holes the length of the joint is then cut, the tools are pulled up to the same position again, turned through an angle of 90°, if four rows are to be cut, and the operation is repeated.

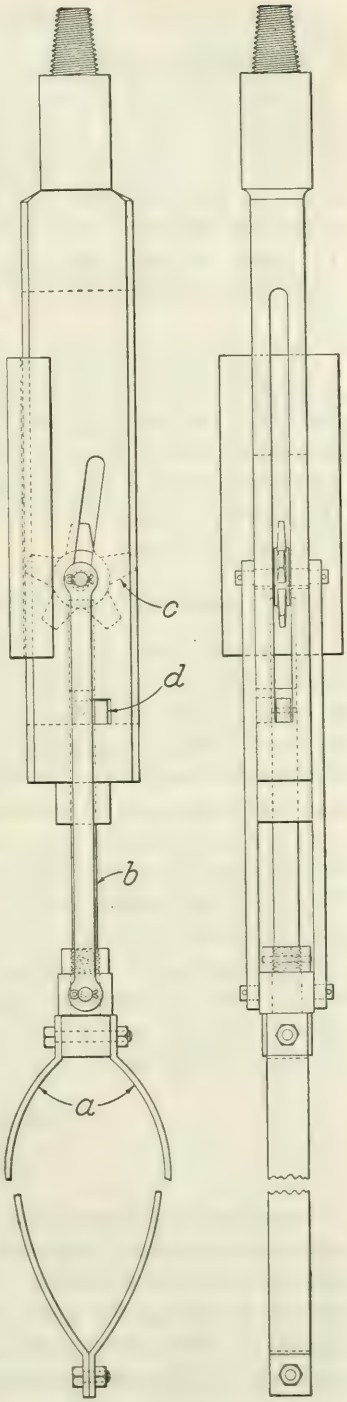


FIGURE 2.—Star perforator; *a*, Spring; *b*, mandrel; *c*, knife; *d*, lug.

BRINKMAN PERFORATOR.

The Brinkman perforator, shown in Plate V (p. 18), was invented and patented by J. J. Brinkman. It is a single-knife machine and one of the first used in the California oil fields. This machine is used on tubing in order to control the placing of the holes. The knife is a 5 or 6-point wheel (Pl. V, *A*) rotating on a pin, and the cutting edges are made to give whatever size or shape of hole is desired. In order to avoid making the holes too close together, the small wheels are made with five points, whereas the larger wheels have six.

When this perforator is being lowered into the well, a clamp, *a*, is placed on the mandrel *c* to hold the knife *d* down to keep it from cutting. On reaching the bottom the weight of the tools causes the mandrel *c* to slip through the clamp *a* and push the knife *d* up along an inclined slot, *e*, out against the pipe. A coil spring, *f*, then holds the knife *d* up in place so it will catch in the casing and cut through when driven down.

RECOMMENDATIONS AS TO SINGLE-KNIFE PERFORATORS.

This perforator or any of the other single-knife perforators mentioned above are probably the most desirable for small companies to own. Many small companies do not find it necessary or desirable to have a machine made for each different size of casing to be cut. Adjustable backs can be made for this type of perforator so that one perforator can be used for several sizes of casing.

It is not advisable, however, to go beyond a certain limit with this building-up process. Ordinarily, the next size casing above that for which the perforator is built is as large as should be attempted. The mandrel is thrown out of center more and more as the diameter of the machine is increased by building up, until there is so much friction on the working parts that they do not function properly. Also, after the oil comes into the well, the spring may not have friction enough on the pipe to force the knife up into cutting position.

DOUBLE-KNIFE PERFORATORS.

MACK PERFORATOR.

The Mack perforator, shown in Plate IV, *B* (p. 11), sometimes called the Graham perforator, was one of the first types to perforate two rows simultaneously. The mechanical action that operates the knives is similar to that of the single-knife perforator shown in figure 1. When the machine is starting into the hole the spring *a* (see Pl. IV, *B*) is pushed over the lug *b* and rests against the bottom of the machine as long as the tools are being lowered. To begin

cutting, the tools are raised until the mandrel *c* is pulled up through the spring *a* far enough to permit the lug *b* to catch the spring and keep it from moving up along the mandrel when the tools are lowered again. The spring then forces the mandrel up until the slotted or grooved part *d* comes in contact with the side irons *ee*, through which the pins *hh* in the wheels are inserted. The knives are pushed up the inclined slots until they come in contact with the casing and are forced through.

This machine differs from other wheel perforators in that the wheels are not all one piece, but have the teeth inserted in a round body, *f*, with tapered dovetailed grooves. The teeth are driven in snugly from one side only. Even should the teeth become loose they can not work out at the side, because of the side irons *ee*. The pins *hh* are prevented from working out by a screw placed radially in the wheel.

Rollers, *gg*, are inserted on opposite sides of the body of the perforator to reduce friction and wear.

In using this machine, experience has shown that care must be taken in adjusting the length of the knives. If they protrude through the casing shell too far, the casing metal at the top of the hole will either be pulled in as the cutter withdraws, as shown in Plate II, *B* (p. 9), or else the inserted teeth will be pulled out.

The usual procedure, as with all other types of two-way perforators, is to run the Mack perforator on a drilling line.

BASCH PERFORATOR.

The Basch perforator (fig. 3), a comparatively new machine, also cuts two rows of holes in opposite sides of the pipe simultaneously. As in other wheel perforators, the wheels are generally five-point or six-point. The cutting edges of these wheels are made in various designs to produce any size or shape of hole desired. The type of knife that has been most commonly used in general practice cuts a rectangular hole with the longest dimension lengthwise of the joint.

Two springs, *aa*, one on each side of the tool, adjusted to fit the casing that is to be cut, actuate the knives *dd*. While the machine is being lowered into the well the knives are held in the center of the machine and do not touch the pipe. The controlling mechanism is shown in detail in the lower right-hand corner of fig. 3. The pin *b*, which is operated by a coil spring, is pulled out until the slot *c* in the side iron *f* can be pushed up into the position shown in the upper right-hand corner of the figure. When it is desired to begin cutting, the perforator is pulled up a few inches, and on account of the springs *aa* holding the side irons *f* stationary, the pin *b* is

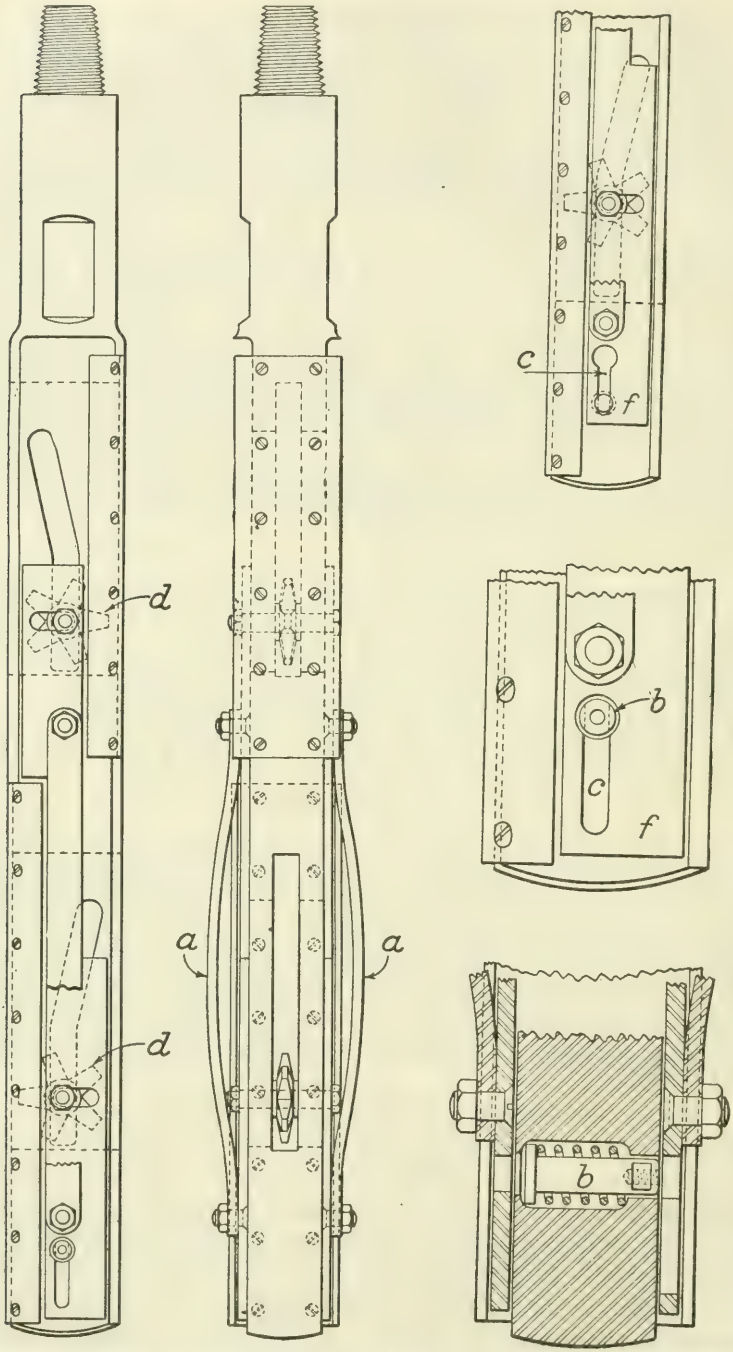


FIGURE 3.—Basch perforator. *aa*, springs; *b*, pin; *c*, slot; *dd*, knives; *f*, side iron.

brought up to the top of the slot in the side iron *f* where the pin will spring back to its original position. The springs *aa* are then free to push the knives *dd* into position for cutting as the machine is lowered. As long as the perforator is forced down, the knives cut, but when it is pulled up, the friction of the springs *aa* on the casing pulls the cutters *dd* down the inclined slots out of cutting range of the casing. This type of machine can not be lowered again without cutting, unless it is pulled out and the springs refastened by the small spring pin *b* at the bottom of the perforator.

If the pipe to be cut is smaller in diameter than that at the top of the well, the machine is fitted with double-spring lugs similar to *b*, and the springs are held in place by one of the lugs in the bottom of the machine until the adapter is reached. As the slots in the iron bars to which the springs are attached are of unequal lengths, one spring is released while the other spring still holds the knife in the same position. As previously explained, to release this spring the tools must be raised a few inches when it is desired to begin cutting.

CRITICISM OF DOUBLE-KNIFE PERFORATORS.

The only criticism that has been made against the double-knife perforator is that in a few wells the casing was flattened by the strain exerted on opposite sides in cutting, which caused difficulties in subsequent operation of the well. However, the casing in wells where this occurred was of the lighter variety and is now not placed in many wells.

IMPORTANT CONSIDERATIONS IN THE SELECTION AND USE OF A PERFORATOR.

The chief requirement to be considered in machines for perforating work is rigidity. The machine should be made of as few working parts as possible, and these should be as simple and solid in construction as permissible. In many wells, owing to the "spring" or give in the casing and to the character of the casing material, the work is so heavy that all the holes must be made by using a "jerk line" in the same manner as when "spudding in" a well. However, this procedure places a severe strain on the machine, and unless it is capable of withstanding such rough usage much time will be lost in pulling it up to make repairs.

Wherever possible, when consistent with the particular perforator to be used, the writer would recommend the use of a drilling line instead of tubing. In most instances a saving in both time and material will result.

When tubing is used it is important, because of the jumping and jerking of the tools, that the elevators be bolted together in order to prevent their becoming unlatched and dropping the tubing. For

the same reason a suitable clevis should be used on the tubing hook, to prevent accidental release of the elevator links when slack is run off on the tubing line.

Nearly all inventors of perforators claim that their machines are absolutely positive in the results obtained, but some of the best types have at times failed to do the work intended. As a result, some potential producing wells were kept from producing for some time, and some were even abandoned. Upon pulling the casing, the trouble was accounted for by the casing not being perforated (see Pl. I, *A*) or perhaps only partly so. Before a well is abandoned all doubt should be removed as to whether lack of perforations are the cause of nonproduction.

SHAPE OF KNIFE.

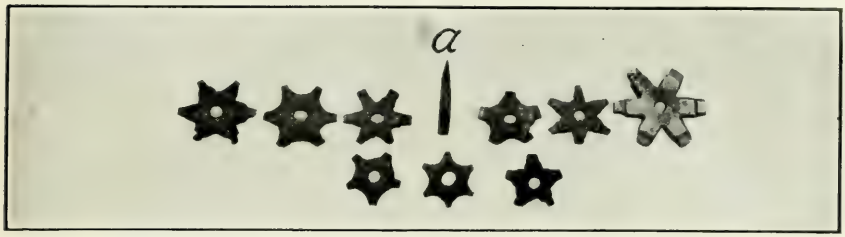
In addition to exercising great care in selecting a sample length of casing for trying the perforator, and in examining the knife-edges to see that they are sharp, it might also be well to consider what shape the knife should be to insure the best results. The type of hole desired, of course, will govern this point. A knife that will punch the casing the easiest may not produce the type of hole desirable for the particular district where the well is situated.

METHODS OF CUTTING HOLES OF VARIOUS SHAPES.

Much experimental work has been done by the various inventors to produce different sizes and shapes of holes which were expected to be of some advantage in different localities. By shaping the cutting edges of the knives, different results were obtained, but up to the present time the clean-cut rectangular hole has been the most used. To make this kind of hole, the face of the knife is ground flat and the edges are all left sharp. Various modifications are made by rounding off certain edges of the knives so that the metal is only partly cut away. This produces what the operators term a "shutter" perforation; a casing perforated in this way is shown at *b*, in Plate VI, *A*. A knife shaped like a chisel point (see *a*, in Plate V, *A*) will produce a slit with the cutting rolled back on each end, as shown at *a* in Plate VI, *A*. The knife producing this perforation, however, was flattened in the opposite manner from that indicated by *a*, Plate V, *A*. With one of the long edges of a rectangular-faced knife rounded off, a narrow slit will result, and the piece of metal thus cut will be pushed back like a shutter.

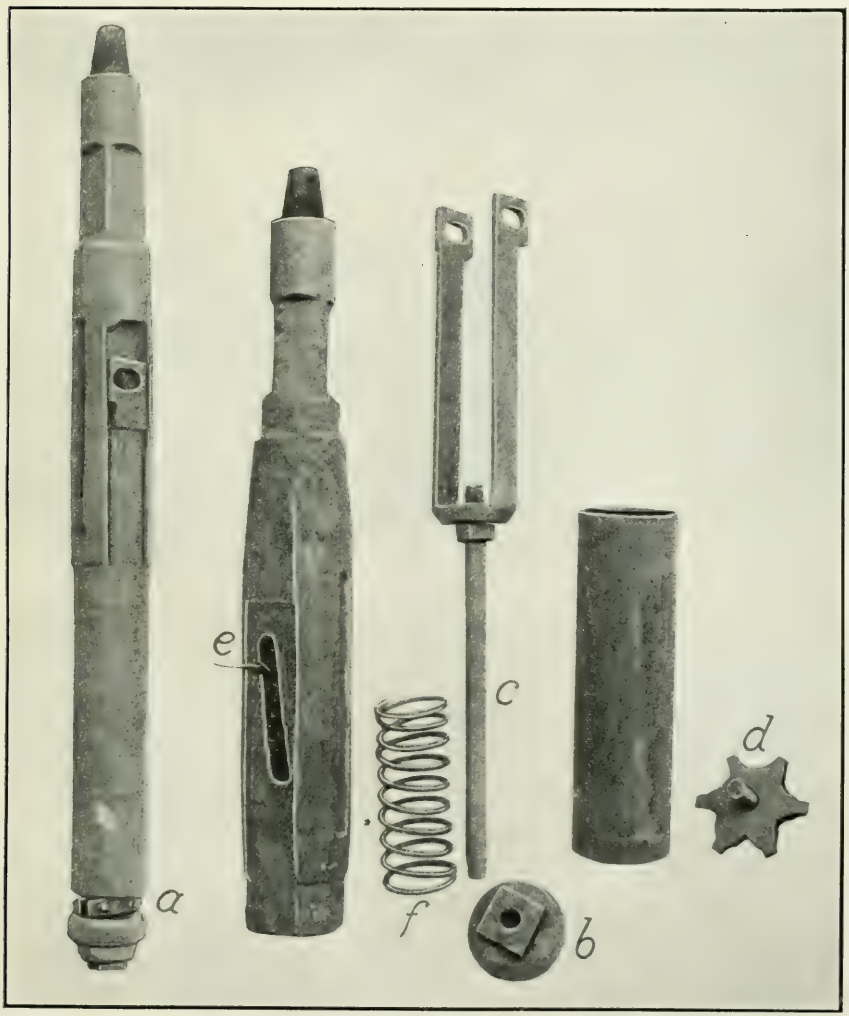
NECESSITY OF USING A GOOD GRADE OF PIPE.

In experimenting with different machines to make the various types of perforations, the best results were obtained by using good steel pipe. With iron pipe or poor grades of steel, often a lump is



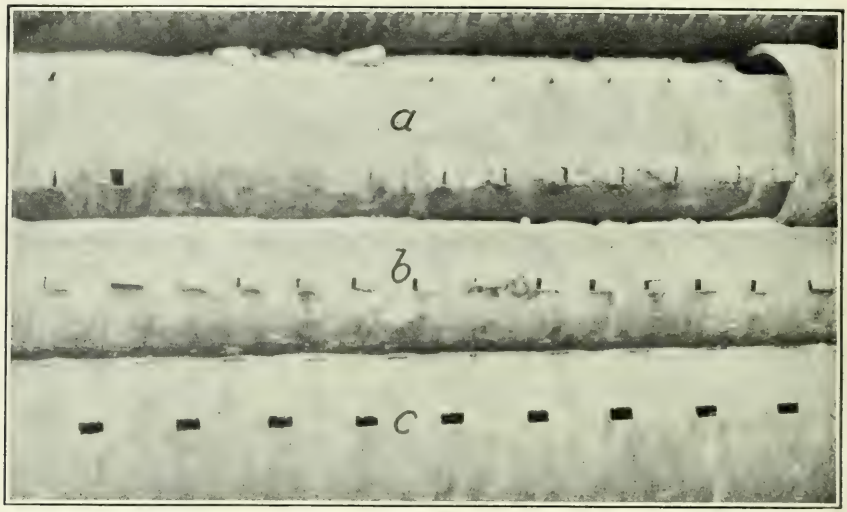
A. FIVE-POINT AND SIX-POINT WHEEL KNIVES USED IN CONNECTION WITH BRINKMAN PERFORATOR.

a, Side view of wheel showing chisel point.



B. BRINKMAN PERFORATOR.

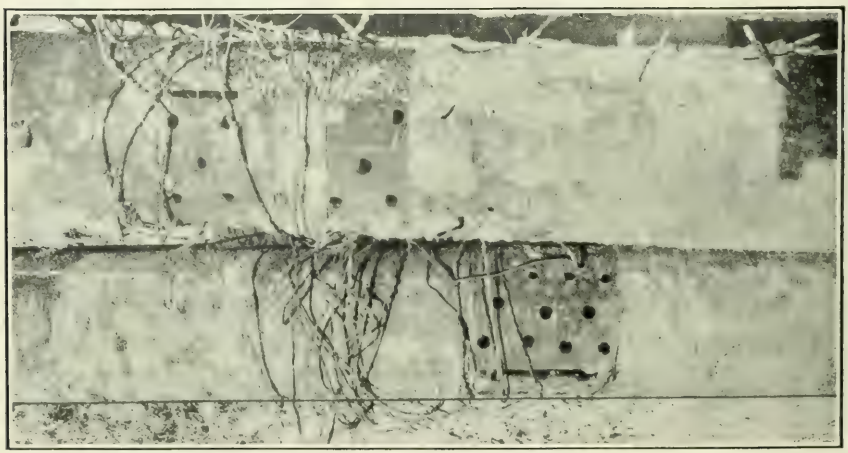
Figure at left shows machine assembled without the knife in place. Other figures show the parts.



A. CASING PERFORATED IN WELL.

a, Shows results of using knife with chisel cutting edge; *b*, hole made with top edge of knife rounded off, producing the so-called "shutter" opening; *c*, hole made with square-faced knife, all edges sharp.

B. TEN-INCH SHOP-PERFORATED PIPE WITH SLOTTED HOLES ½ INCH BY 2½ INCHES.



C. SCREEN PIPE THAT HAS BEEN PERFORATED IN THE WELL.

formed on the outside with a crack in the middle of the convex surface.

Where the holes have been punched close together, in the poor grades of casing they often break into one another. Such conditions in a well are unsatisfactory.

EXPERIMENTS ON FLOW OF SAND THROUGH VARIOUS OPENINGS.

Experiments on flow of sand with different shapes and sizes of perforations indicate, in a general way, what kind of movement may be expected under a given set of conditions. In experimenting with dry sand the gradient, or angle of repose, that sand will assume naturally when heaped in a pile, is 1.5 to 1. This gradient will govern the flow through a horizontal slot, where the walls of the slot have sufficient thickness, but the same slot turned in a vertical position will, regardless of its thickness, permit sand to flow through readily. Thus, a slot 1½ inches long cut horizontally in pipe one-half inch thick will not let sand through unless its width is increased to about three-eighths of an inch, but a vertical slot of the same length will let sand run through freely provided it is wide enough to permit the grains to pass. When sand is wet, the natural slope is 2 to 1, hence the slot would not need to be so wide before the sand would start to run in; the minimum being about one-fourth of an inch for pipe one-half inch thick. Obviously, horizontal perforations tend to hold out sand more than vertical perforations would. For the same reason, the various types of "shutter" perforations will keep the sand out of the well unless it is forced in by gas pressure and fluid pressure. These two factors are always unknown quantities, and are also constantly changing. For this reason, the choice of screen and perforated pipe has to be a matter of trial.

FOUR-KNIFE PERFORATOR.

A proposed improvement on the double-knife perforator is the four-knife perforator, which punches four rows of holes at right angles to each other. For accurate spacing and for saving time this machine has a decided advantage over the others mentioned, but is not approved by some operators, because, it is claimed, the machine lacks rigidity, and the mechanism is somewhat complicated.

SHOOTING FOR PERFORATING.

A novel method proposed for perforating pipe, which may be considered as perforating in the well, without the use of a machine, is that of exploding a charge of explosive in the well after the casing is set.

The pipe is first cut in the shop, each perforation being about ⅜ by 1½ inches, parallel with the length of the joint. The upper edge is not cut, so that the strip of metal forced out is still intact at the top. The strips are then pressed back into place, making the pipe as smooth as before cutting. The well is then drilled as usual, with this pipe on the bottom of the oil string; such pipe has the advantage, as compared with the ordinary shop-perforated pipe, of not letting sand run in during the drilling. When the hole is finished it is not necessary to run a perforator into the well or pull out the casing to put on a shop-perforated pipe or screen pipe. To open up the perforations a light charge of explosive is shot off in the well, and the explosion forces out the strips of metal. This method is still in the experimental stage, and has not been successfully demonstrated as yet. It has several advantages in its favor, and more extended experiments might be worth while.

SHOP-PERFORATED PIPE.

Those operators who wish to do away with the more or less uncertain conditions or results obtained by perforating casing after it is in the hole, or who desire smaller perforations and more of them than can be obtained satisfactorily with casing perforators, are using what is termed shop-perforated pipe. The perforating is usually done in the machine shop with a drill press or similar machine. The great advantage is that the work can be inspected and any defects remedied before the casing is placed in the hole. Round holes are common, also narrow slots cut perpendicularly (see Pl. VI, *B*). The size and number of holes used depend on the character of the sands and the gravity of the oil in the well. In general, smaller holes are being used where the sands are fine grained and the oil of high gravity.

ADVANTAGES.

The advantages gained in using shop-perforated pipe outweigh any extra trouble and expense that may be encountered when setting it in the hole. The method is, therefore, to be recommended wherever possible in preference to perforating in the hole, for the following reasons:

1. Joints of casing at different depths can be given different sized openings, according to the character of the sands penetrated, which can be ascertained by merely keeping a log of the well.
2. The spacing of the openings is symmetrical.
3. The openings are clean cut.
4. The spacing of perforations can be so arranged as to give the maximum total inlet area without sacrifice of necessary strength for resisting collapse.

5. For the same size and spacing of holes the casing is weakened less if the holes are cut than if they are punched.

6. There is less chance of flattening the pipe or making it oblong.

ROUND HOLES.

As explained in a subsequent discussion of horizontal perforations, round holes tend to hold out sand until the diameter of the hole has been increased beyond a certain limit. This limit depends on the thickness of the casing and the angle of repose of wet sand. The force of the flow into the well will also govern the amount of material carried in. As this is an unknown factor, it would be impossible to calculate theoretically the size of holes necessary in any given territory; the proper size of hole has usually been determined by experience. For water wells, small shop perforations have met with great success, whereas the larger perforations made by machines in the hole brought about the final abandonment of some wells. The latter permitted so much sand to come in that the wells could not be operated economically.

SHUTTER PIPE.

A recent invention that might be classed with shop-perforated pipe is what is called Layne & Bowler shutter pipe. This is manufactured by the Layne & Bowler Co., and is described as being particularly adapted for keeping sand from running into the well. The cutting is done with a special tool in the machine shops. The tool does not cut away any material, as most perforating tools do, but forces a horizontal slit in the casing of any width desired. The bulges caused by the perforating are nearly as large and sometimes are fully as large as the couplings. Therefore, any "shells" or hard formations through which the drill has passed should be reamed out, otherwise it may be difficult to set this type of perforated pipe.

ACETYLENE PERFORATED CASING.

The acetylene torch is used with great proficiency in perforating casing, the usual custom being to cut a narrow, longitudinal slit 2 or 3 inches long. The width of the slit can not be less than one-eighth inch, because the flame can not be made any smaller and work efficiently.

This method has proved to be very efficient as regards the cutting, but the results obtained are not always as good. Small globules of molten steel form along the inside edges of the hole and harden there, making a rough surface on the inside of the joint. This is particularly detrimental to such operations as swabbing to increase production.

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METHODS OF SETTING SHOP-PERFORATED PIPE.

CONDITIONS GOVERNING METHODS.

In general, there are several very important factors that will govern the methods to be used in setting shop-perforated casing and the various forms of screen pipe. They are as follows: (1) The condition of the hole after "drilling in," that is, whether it will "stand up" or cave; (2) whether or not mud-laden fluid has been used; (3) the gas pressure in the well; and (4) method of drilling, whether standard or rotary.

A brief discussion of those methods which have met with success in universal practice follows.

SETTING A LINER WITH TOOLS.

Probably one of the first methods used for setting liners of shop-perforated casing and screen pipe was to run the liner into the well on a drilling line, below the tools. A suitable grab hook was used, or a bolt inserted in an opening drilled through the water course of the bit served as a special tool for lowering the casing to bottom. If the hole was in such condition that it stayed clean sufficiently long, or if the weight of the pipe was not too great, that is, not more than two or three joints, this method was satisfactory. Should there be any element of risk, however, a more efficient method should be employed, even if the cost be greater.

"DRILLING IN" WITH SHOP-PERFORATED PIPE.

Another method of setting shop-perforated pipe is to place it on the "oil string" before penetrating the oil strata and then drill in the usual way.

DISADVANTAGES.

The chief disadvantages of this method are as follows: (1) Some difficulty is generally caused by sand running in, sometimes in such large quantities that drilling proceeds very slowly. (2) As a rule the hole is kept full of water in order to prevent caving, therefore the true value of the gas and oil sand can not be estimated. (3) It is difficult to tell the character of the material the drill is passing through, because of the sand running in. (4) When the distance between the oil sand and the bottom water sand is not very great, water may be penetrated unintentionally, with deplorable results. (5) Further, it may not be necessary to have the perforated pipe extend through all the strata in the oil-bearing sand, and it can not be foretold where to put the blank pipe until the hole has been drilled. Therefore, in general, this practice is to be discouraged, except in a field where the bottom of the hole can be predicted accurately and the underground conditions are definitely known.

SETTING SHOP-PERFORATED PIPE AFTER "DRILLING IN."

A plan which has proved more satisfactory than the one just described is as follows: The hole is first drilled through the oil sand, casing being carried along as in ordinary drilling practice. After the well is complete, the casing is pulled out, the shop-perforated pipe put on, and the casing replaced in the hole.

PRECAUTIONS.

Time is an important factor in conducting such work successfully. The quicker the casing can be replaced, the less trouble will be experienced from caving, and the less cleaning there will be to do. For this reason many companies who formerly put in all their casing by daylight now complete this work without stopping.

SCREEN PIPE.

REASONS FOR USE OF SCREEN PIPE.

Before the use and methods of setting screen pipe are discussed, it may be well to consider the conditions under which an operator is justified in using such pipe. When should it be necessary to use screen pipe, which is more expensive than other casing, and aside from its screening properties, does not possess any marked advantage over ordinary shop-perforated casing? Economy is the deciding factor. When a well makes more sand than can be economically handled with a pump, it is necessary to keep the sand from running in so freely; therefore, screen pipe is used. Screen pipe can be obtained with much finer openings than have been produced satisfactorily in the shop-perforated pipe.

The question, "Why can not the sand be handled?" naturally arises. The following are two conditions, often met, which govern this point:

1. The gas and fluid pressure in the oil sand may be so great that more sand is forced into the hole than can be taken care of, causing loss of time, labor, and production in cleaning.

2. The water shut-off may not have been a success and the well may be making large quantities of water. In a well producing much water a very small amount of sand may cause the pump to sand up; and the losses from sanded-up jobs may soon outweigh production. This condition may develop after a well has been producing for some time, necessitating redrilling and replacing the ordinary perforated casing with screen pipe, to hold back the sand. Were the well free from water, or nearly so, a screen would not be required, and might be detrimental rather than helpful. The water acts to transport the oil, carrying it through the sand[a] packed around the outside

[a] Lewis, J. O., Methods of increasing recovery of oil from wells: Bull. 148, Bureau of Mines, 1917, pp. 92–117.

of the screen and through its meshes into the well. Without the assistance of the water the oil, owing to its viscosity, might not run through the packed sand into the well, or at least not run in fast enough to give the maximum yield.

Screen to hold back the sand also seems necessary where the oil sand is broken by alternate layers of shale or clay. By permitting the sand to run in freely, a cavity is formed and the unsupported layers of shale or clay cave. The cavings fall down alongside the casing, plug up the perforations, and seal off the oil sand, unless there is sufficient outside pressure to force the oil into the pipe. The rapid decline of some wells is attributed to the conditions brought about by such operations. The trouble occurred, however, after the well had produced for a time, thus indicating that the flow of sand had not been correctly handled. The foregoing statements are corroborated by the fact that experience in drilling with shale or clay placed around the casing to prevent sand running in has shown that it is difficult to bring such a well to normal production after completion.

ADVANTAGES.

If it be taken for granted, then, that the operator desires to limit the amount of sand entering the casing, and can produce more oil by doing so, several other advantages in favor of screen pipe may be enumerated, as follows:

1. Removal of sand is one of the causes of pipe collapsing, because when a cavity is formed the overlying rock may settle or move and crush the pipe. Also, cavings from certain strata, such as clays and some shales, may have a decided clogging effect, thus keeping out the oil. Hence, screen will prolong the life of the well.

2. While the sand remains in place the danger of water breaking in from above is materially lessened. Gradual withdrawal of the sand around the pipe naturally weakens the immediate overlying stratum and lessens its resistance to the water pressure.

3. The well is kept clear from bottom to surface, thus saving the time and labor of cleaning.

4. Keeping the column of oil free of sand prolongs the life of pump and valve seats.

5. Cleaned oil is run directly to storage instead of into sumps to settle out sand; the latter practice usually results in losses from evaporation of lighter fractions of oil.

DISADVANTAGES.

As already intimated, before deciding to use screen pipe the possibilities of its ultimate success should be carefully considered. There are conditions under which the use of screen pipe is not war-

ranted and, in fact, may result in a practical loss, as in territory where it is necessary to permit sand to come in with the oil to maintain the maximum production. If screen pipe is placed in a well, and afterwards perforating is necessary, the results obtainable by perforating in the well will be uncertain. The actual practice has often proved disastrous. The pipe has so many holes drilled in it that a perforator causes the pipe to break from one hole to another, leaving large rough openings. (See Plate VI, *C*, on page 19.)

DETERMINATION OF WIRE MESH.

Determination of the proper size of wire mesh to use for screen pipe so far has depended on actual experience, various sizes being used in any given locality until the particular size giving the best results is determined. In general, it is found that a coarse screen will give the best results in coarse-grained sand and heavy oil, whereas the finer sands and lighter oils produce best, or more economically, through the finer-mesh screens. The important thing to consider is just how much sand can be handled economically. As long as there is little or no water in a well, a considerable amount of sand can be pumped with little trouble and expense. Again, the perforations should not be so fine as to wholly prevent sand from coming in. If this condition prevailed, the sand would soon pack around the outside of the pipe, the finer grains filling the interstices of the large grains, and would seriously retard the flow of oil into the well. The mesh of screen considered correct is that which permits sand to be brought into the well when the various methods used for increasing production, such as swabbing, etc., are made use of. Swabbing removes the finer material from the pore spaces between the coarser grains of sand that collect around the outside of the pipe and washes this fine sand into the well where is can be bailed out, thereby usually increasing the flow of oil into the casing. This has been demonstrated on leases where swabbing is a common practice. After swabbing there is usually ten or more feet of sand to be bailed out, and the production of the well increases for a time.

RESULTS PRODUCED BY PRACTICE IN DIFFERENT FIELDS.

In some wells where large quantities of sand have been permitted to flow into the well for an indefinite length of time, conditions underground have caused a shifting of the casing which resulted in its ultimate collapse. This result is not invariable, however, as attested by the North McKittrick field and Kern River field of California, where certain wells have pumped large quantities of

sand for years, without any apparent disadvantage; in fact, the production of the well was not worth while until an appreciable flow of sand was started.

To obtain profitable production, operators sometimes have to resort to methods that may ultimately lead to poor results. However, there seems to be no other recourse than to produce in this manner as long as possible and then redrill when the well fails. The practice of placing screen pipe or shop-perforated pipe on a full-length string of casing and hanging the casing on clamps under a slight strain has occasioned a marked decrease in the amount of redrilling necessitated by shifting casing.

Operators in any given field become accustomed, by experience, to the use of a certain mesh and type of screen, the type preferred varying in different parts of the United States. Each field may be said to have a standard type of screen. For instance, operators in the southern Texas fields use a very fine mesh, 0.008 to 0.014 inch, suited to the very fine-grained sand and the light (22° Baumé) oil of those fields. In the McKittrick and Kern River fields of California a coarse-mesh screen, or a perforated pipe with fairly large holes, is commonly used. The perforations vary in width from one-eighth to one-half inch; to a great extent a standard has been established for each separate locality.

EFFECT OF UNDERGROUND WATERS ON WIRE SCREEN.

The material of which a screen is made, as well as the size of mesh, is an important consideration in choosing a screen. Acid or alkaline waters, having disastrous effects, are encountered in some places. For this reason a sample should be taken of any underground waters present, and an analysis made. From this information a material resistant to the corrosive action of the water can be chosen. The materials most commonly used for wire screens are brass and galvanized iron. As these two materials have not always met the requirements successfully, it is evident that there is justification for more experimental work along this line. Repairing a well after the wire screen on the pipe has been destroyed is an expensive procedure, not only as regards the repair work, but also because production is temporarily halted.

PRESERVATION OF SCREEN PIPE FROM CUTTING ACTION OF SAND.

Besides the corroding effect of underground waters on screen pipe, which often assists in its ultimate destruction, the cutting action of sand carried through the perforations under high gas and fluid pressures also has a very deleterious effect. Therefore, in flowing wells it is necessary to control the flow of fluid into a well, not only for the

sake of increasing the life of the well itself, but also for preservation of the pipe. The great cutting action of rapidly moving sand in flowing wells has been demonstrated in wells that have gone "wild," where the tools were permitted to hang over the hole in the path of the blast. Solid pieces of steel have soon been cut and worn away. Evidently it is necessary to take precautions to curb the rush of fluid and sand, or the perforated casing will soon be destroyed.

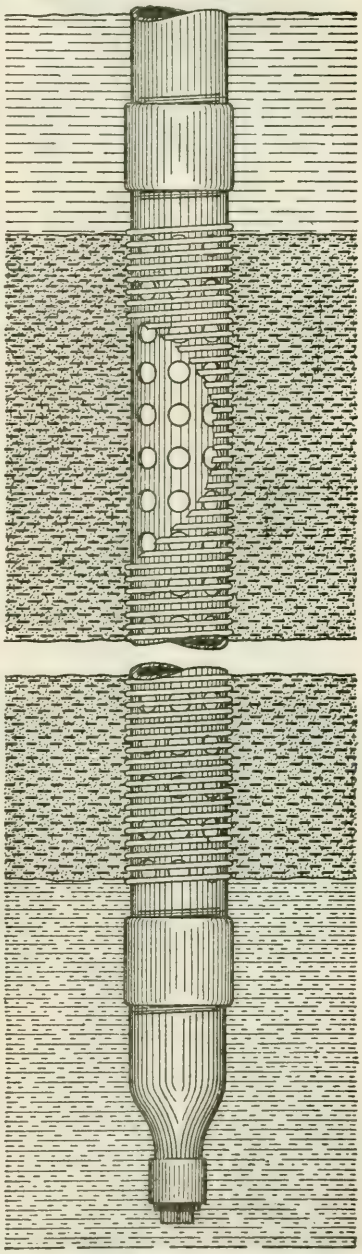


FIG. 4.—Typical screen pipe wrapped with round wire. Patented screens similar to this are made using different shapes of wire.

METHOD.

In order to control a flowing well, or hold the pressure in and not permit it to dissipate or cause the well to flow wild, a "flow nipple," or "bean," as it is sometimes called, is placed in the lead line that connects with the tubing. This "flow nipple," or "bean," is made of a solid piece of steel through which a small hole is drilled. The hole varies from three-eighths of an inch in diameter up to any size desired, depending on the gas pressure in the well.

TYPES OF WIRE-WRAPPED SCREENS.

ROUND-WIRE SCREEN.

The pipe is drilled full of holes about one-half inch or three-quarters of an inch in diameter with 4 to 6 inch centers, and then wrapped in a lathe with steel, galvanized iron, or brass wire. The size and spacing of this wire depend on the gravity of the oil and the size of the grains of sand in the well where it is to be used. The plain screen (fig. 4) is wrapped with round wire.

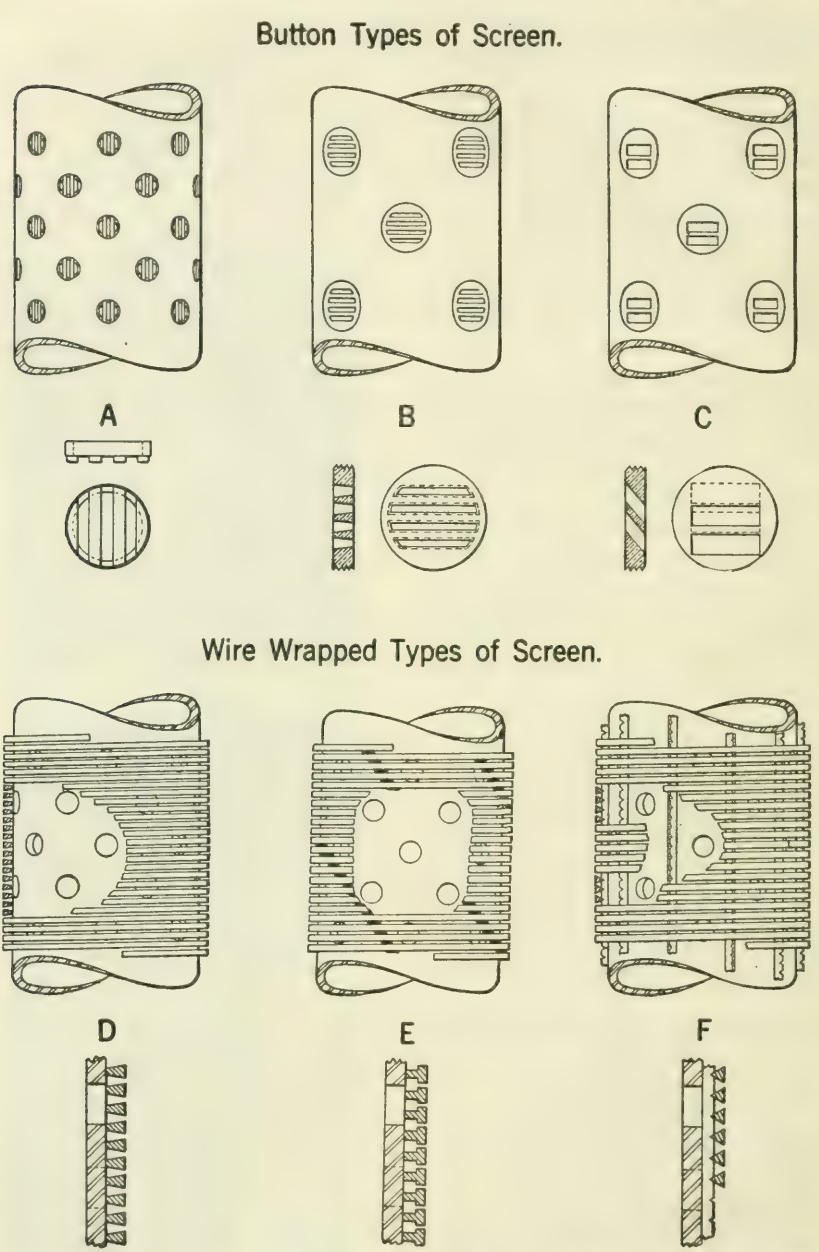


FIGURE 5.—Types of screen pipe. *A*, McEvoy screen; *B*, Layne & Bowler button screen, keystone openings; *C*, Layne & Bowler button screen, shutter openings; D, Layne & Bowler keystone wire-wrapped screen; E, Getty screen; F, Stancliff screen.

LAYNE & BOWLER SCREEN.

A patented screen (see D, fig. 5), sold under the name of Layne & Bowler, is wrapped with rectangular wire having the outside edge wider than the inside edge. This is also known as the "keystone" wire-wrapped screen pipe. The purpose of this method of construction is to permit sand that passes the outside edge to go on through, so that the mesh will not become clogged inside. The wire is wrapped on horizontally and is held in place by solder.

GETTY SCREEN.

The Getty screen, as shown in E, figure 5, is similar to other wire-wrapped styles except in the shape of the wire, which is shaped like the letter "T." A spacing lug is placed about every $\frac{3}{4}$ inch on the wire to regulate the spacing and assist in maintaining the mesh after the pipe is placed in the well.

STANCLIFF SCREEN.

The Stancliff screen, shown in F, figure 5, has a triangular-shaped wire wrapped on perforated casing, this wire being held away from the casing shell by other triangular wires running vertically. The vertical wires have small notches cut in them by which the proper spacing is maintained in the horizontal wire.

CARBORUNDUM SCREEN.

In an effort to overcome the conditions that are met with in some of the Gulf Coast oil fields, C. N. Scott, of the Texas Co., has devised a screen called the "carborundum screen" (fig. 6). The screen is

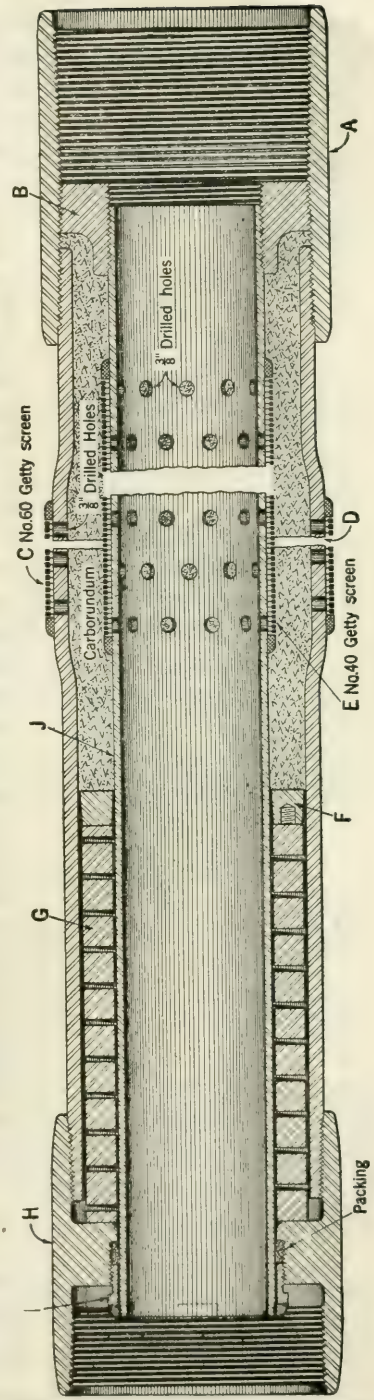


FIGURE 6.—"Carborundum" screen devised by C. N. Scott.

intended to overcome the cutting action of the fine sand, carried into the well under high pressure, which destroyed other types of screen. It is not uncommon to have wells sand up in six to eight months' time, making redrilling necessary to restore the production.

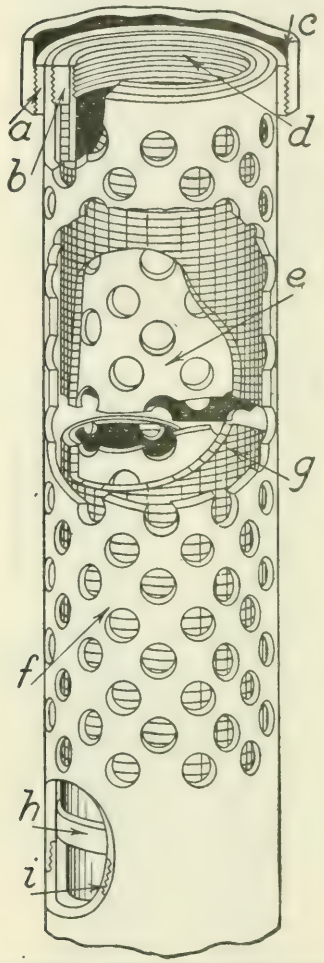


FIGURE 7.—Mack well screen (patented). *a*, Collar between liner and jacket; *b*, brass collar, left-hand thread; *c*, liner which seals off in casing; *d*, inside right-hand thread for tap to remove screen; *e*, inside perforated pipe; *f*, outside perforated jacket; *g*, screen wire; *h*, brass seat for screen to rest on; *i*, inserted joints, used in place of collars.

The screen is made by placing a No. 60, $6\frac{5}{8}$-inch Getty screen over a No. 40, $3\frac{1}{2}$-inch Getty screen and filling the annular space between with carborundum. Details concerning the construction are shown in figure 6. A special steel adapter ring, B, is screwed into a $6\frac{1}{2}$-inch, 8-thread coupling, A. The $3\frac{1}{2}$-inch liner pipe J with the No. 40 screen E is then screwed into the ring B; the $6\frac{5}{8}$-inch pipe with No. 60 Getty screen C is placed over the smaller pipe and screwed into the coupling A. The screen is filled with carborundum, rolled and shaken in order to work down the carborundum filling thoroughly, pack the space solidly, and fill the $\frac{3}{8}$-inch holes on the inside of the outer screen. A space of nine inches is left between the top of the carborundum and the top of the pipe. On top of the carborundum a steel alining ring, F, is placed, and on this a steel spiral spring, G, 14 inches long when uncompressed. The special steel coupling H is then screwed onto the outside pipe, thus compressing the spring G. Suitable packing, such as lamp wicking, is put in the annular space between the steel coupling H and the $3\frac{1}{2}$-inch casing J, and the coupling is screwed down to make a tight joint with the steel packing gland. I. This completes a single joint of this type of screen, which measures a little over 20 feet in length. On account of having couplings on each end, the joints are screwed together with short nipples.

MACK SCREEN.

A well screen recently invented and patent by J. O. Mack consists of a wire-wound screen, square wire being used, covered with an out-

side jacket of shop-perforated pipe (fig. 7). The screen is set on a ring of brass or a shoulder to hold it in place. Sections of any length desired are used in building up the total length of casing required. The top, or last section of screen pipe placed, is fitted with a left-hand thread. This is intended to permit the screen to be removed at any time it is necesary to do so, by running a string of pipe into the well, unscrewing the top liner and lifting the sections out. The practicability of this device has not been determined at this writing.

TYPES OF BUTTON OR DISK SCREENS.

MCEVOY SCREEN.

The McEvoy screen (A, fig. 5), another patented device, is made by inserting perforated brass disks, of whatever mesh desired, in holes previously drilled in the pipe. The disk is inserted under a pressure of 1,000 pounds per square inch, which the manufacturers claim leaves the strength of the pipe unimpaired. The perforations are placed perpendicularly, not horizontally, as in the types of screen previously mentioned. The disk is held in place by swaging the edge of the hole against a shoulder on the disk. The manufacturers claim, as one of the advantages of this make of screen, that it can not be damaged while being set in the hole, as the buttons are flush with the outside of the pipe; the wires, being vertical, will not catch on the walls of the hole and become damaged or clogged. The disks or buttons are not thick enough to be flush with the inside wall of the casing.

LAYNE & BOWLER BUTTON-TYPE SCREEN.

One of the latest types of screen (B, fig. 5) recently put upon the market is an invention of the Layne & Bowler Corporation. A button or brass disk about 1½ inches in diameter is screwed into a hole in the casing, the holes being spaced about 6 inches apart. A tapering thread helps hold the disk in place; it is also center-punched on the edge to give added assurance of its not becoming loose. The disks are made the same thickness as the pipe, so that the disk is flush with the inside and outside wall of the casing. Two types of screen are produced—one (B, fig. 5) resembles the wire-wrapped Keystone style and the other (C, fig. 5) a newer shutter opening.

The manufacturers plan to do the work of fitting the brass disks at the property where the casing is to be used. A portable machine for drilling and tapping threads in the customer's own casing will be sent for the purpose.

The shutter opening is designed to prevent sand running into the well unless forced in by gas or fluid pressure. The openings are, however, much wider than those used in other types. In certain localities where the production can not be maintained without permitting sand to come in with the oil, the shutter condition is reversed. Although some operators might feel justified in using such a screen in this manner, it would be far more economical to use the plain shop-perforated casing.

ACETYLENE-WELDED LINERS.

In drilling very deep wells it is not uncommon for the hole to become so small by the time the oil sand is reached that it is difficult to accomplish the best results. Therefore, in order to set as large a liner as possible, the joints are welded together with an acetylene torch, no couplings being used. Only a few instances of this kind have been noted. Where any welding has to be done at the top of the well, the risk on account of fire makes this practice undesirable. Also, a liner that is set in, unsupported at the top of the well, is more or less likely to be shifted and broken off or collapsed.

INSERTED-JOINT PIPE.

Pipe with inserted threads is also employed to eliminate the use of couplings. The strength of the pipe is materially weakened when inserted joints are used, and their use is not generally recommended.

METHODS OF SETTING SCREEN PIPE.

Several methods of setting screen pipe are in general use, depending on the drilling system used. With the rotary method of drilling, the hole is drilled to the depth required and the screen is placed on the oil string and run in. Washing the mud completely out of the well before the casing is set is absolutely necessary. Special methods of doing this are described in a subsequent connection. If any mud is permitted to remain behind the screen it will clog up the perforations, and much difficulty will be experienced in getting the maximum production from the sands.

SETTING WITH STANDARD TOOLS.

With the standard cable-tool method of drilling, the screen can be set in the same way that shop-perforated pipe is set. Another method which is used whenever conditions permit and which is particularly adapted for wire-wrapped screens, on account of keeping the wire wrapping from becoming damaged, is as follows: The

screen is used as a liner and must be small enough in outside diameter to pass within the casing carried through the oil sand. The screen is usually plugged at the bottom with a swage nipple or wooden plug. On top is placed a plain joint fitted with a plain casing shoe, upside down and replacing the top collar. This serves as an adapter. The adapter is threaded with a left-hand thread on top, into which a swage nipple is screwed. This liner is then lowered inside the drilling string of casing by means of a string of tubing. When bottom has been reached the outside casing is pulled up to the solid joint on top of the screen, allowance being made for whatever lap is desired. An allowance of 10 to 12 feet can be made for any discrepancies in taking measurements. Then the left-hand thread swage nipple is screwed out and the tubing removed. It is important that this work should be left until the casing has been pulled up to the proper place, to make certain that the screen liner is not moving with the outside casing as the tubing is pulled. Also, sloughing of the walls of the hole around the liner tends to prevent its rotating when an effort is made to back off the left-hand nipple.

The chief requirement for success of this procedure is to keep the outside casing free so that it can be pulled up after the screen is set. Oftentimes this involves no little difficulty. Time is usually an important consideration; for this reason, everything is gotten ready before the screen is started into the well. The tubing is made up in stands of three joints and placed in the derrick ready for immediate use. It may be necessary to move the casing from time to time to keep it free; this can be done while getting ready, but not after the screen has been started in, as the sand would run in and prevent the screen being set on bottom, or else necessitate cleaning the hole. This would cause expense and loss of time. The liner would have to be removed and the main object of this method—namely, to avoid moving the liner through uncased hole, which might damage the wire mesh—would be frustrated.

Occasionally a casing will become frozen; then the screen liner method can not be used, and the only recourse left would be to perforate the casing in the usual way.

"FLOATING IN" METHOD OF SETTING PIPE.

Some operators set the screen liner by a method called "floating in." In this method the oil string is filled with water, then the screen pipe is screwed together at the top of the well, with a wooden plug or suitable iron plug in the lower end, and released to "float" to bottom. Reliance is placed on the water in the hole checking the velocity of the screen's fall sufficiently to protect the screen or the

outer casing against damage. The outside casing is then pulled up to a height that will insure a lap of 10 to 12 feet between the two strings.

DISADVANTAGES.

In some instances when the "floating in" method was used the screen liner failed to set on bottom. The liner either caught in some way going down, or after reaching bottom was held by the outside string and pulled back. In other instances there was apparently too much clearance between the two strings of casing: the screen pipe "floated" to the bottom too rapidly and was damaged by the impact, which also caused slight damage to the outside string, so that the two casings had to be removed and the hole redrilled. Therefore, although this method of setting screen pipe has been successfully employed in many wells, in general it is not to be recommended. Slower but far more efficient methods are available that will not require much additional expense, such as have been explained previously in connection with setting shop-perforated casing and screen pipe.

SETTING SCREEN PIPE WHEN MUD-LADEN FLUID HAS BEEN USED.

Frequently when setting screen pipe or any other type of perforated pipe in a well that has been drilled through the oil sand with mud fluid in the hole, it is necesary to wash the mud out of the well before finally setting the casing on bottom. If there is a strong gas pressure in the well it is not likely that any extra equipment will be needed for this work. The mud-laden fluid should be thinned as much as practicable, and the screen run in as rapidly as possible. The high gas pressure will force the mud out of the sand into the well and then help clear the well of the mud fluid.

WASH-PIPE METHOD OF SETTING PIPE.

CONDITIONS REQUIRING WASH-PIPE METHOD.

The wash pipe (A, Fig. 8) is a pipe of smaller diameter than the casing to be set, usually 3-inch or less, and extends from the surface to the packing device below the perforations, or extends between two packers—one below and one above the perforations. The purpose of using a wash pipe is to conduct the water to the lower end of the screen pipe before it issues through the perforations.

The wash-pipe method of setting shop-perforated casing and screen casing is used where two separate conditions prevail—one, where there is a minimum gas pressure and it is desired to wash the hole free of mud by conducting clear water down through and around the shoe joint of the casing to be set; the other, where there is an excessive gas pressure. In order to keep the well under control

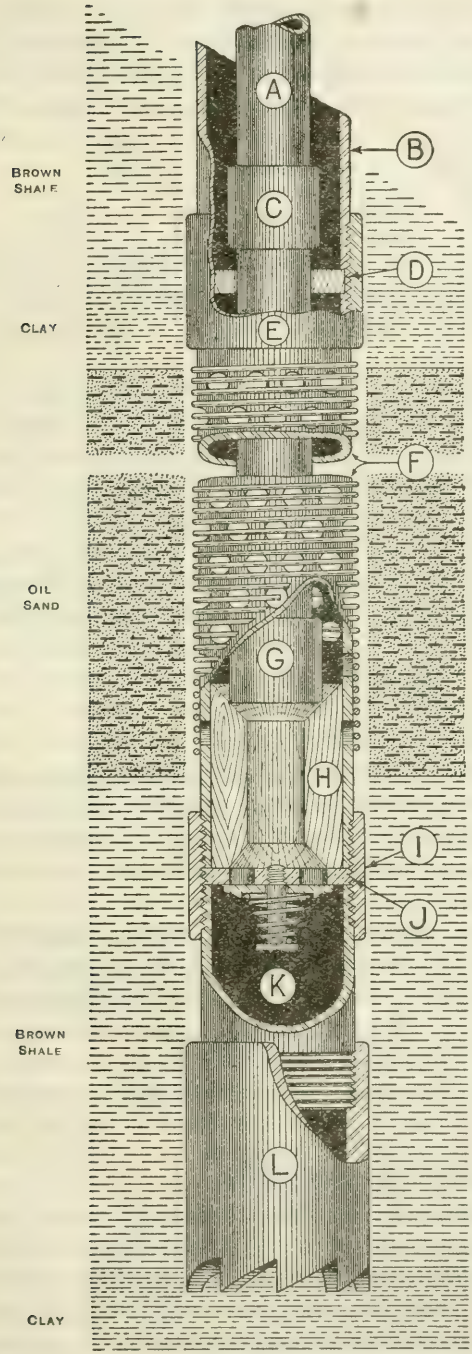


FIGURE 8.—Diagram showing method of setting screen pipe when mud-laden fluid has been used in drilling the well. Is particularly adaptable to wells drilled by the rotary drill.

and prevent a blow-out with its consequent disastrous results, mud fluid has to be circulated at frequent intervals. However, it will often be necessary to clean the hole 20 or more feet below the pipe, and then fill the well with mud fluid again in order to overcome the gas pressure. After the gas pressure has been overcome, the next joint of casing should be put in as quickly as possible.

EQUIPMENT WHEN USING ENTIRE LENGTH OF OIL STRING.

When the gas pressure is not great enough to clear the sand around the hole of mud, or it is impractical, on account of caving, to thin the mud in the well, the following method is in general use (see fig. 8):

To prevent "heaving sands" coming up on the inside of the casing, a back-pressure valve, J, is set below the perforations. On top of this valve a wooden wash plug, H, is set to receive a wash pipe, A, of whatever diameter is desired, usually 2 or 3 inches. The wash pipe should have a coupling on each end (C and G). Some operators have used a packer instead of a wooden plug, with uncertain results. The sand sometimes ran in on top of the packer and made it difficult to remove. The wash pipe should extend from the bottom wash plug, H, to a foot or more above the top coupling, E, of the screen pipe. Within this top coupling a packer or wash ring, D, of some soft material should be placed around the wash pipe to prevent any fluid from going around the outside. By this means the water is carried from the pump down through the bottom of the strainer as the latter is being run into the hole. This will clear the well of sand, and when the strainer is nearly on bottom, clear water can be used to wash the walls free of any mud that may be present.

In some localities where there are shifting sands, operators have found it more profitable to let the entire length of the oil string remain in the hole. A slight strain can be placed on the casing and it can then be clamped up. This will help support the strainer in the bottom, it will not be so liable to shift over or get damaged, and, when redrilling, the chance of removing all of the oil string will be greatly increased.

REMOVING WASH PIPE.

When the outside washing is complete a string of tubing is lowered into the well and is screwed onto the wash pipe. As the wash pipe is being withdrawn, pump pressure is placed on it to help clear the strainer of any sand that may have run inside during the setting. In fact, hydraulic pressure may be necessary to help remove the wash pipe, if sand has settled tightly around it. If the use of pumps to help loosen the wash pipe is unnecessary, the pipe

may be lifted out by using a tubing spear run in on a wire line. It may be advisable to do such pulling with the calf wheels.

If the rotary method of drilling has been used, a rotary shoe (L, fig. 8) or drill bit can be placed on the bottom of the screen to facilitate cleaning.

RECOVERING PART OF OIL STRING.

When it is desired to recover part of the oil string used for setting the strainer, because another string of casing has previously been set on top of the oil sand, the method is slightly modified (see fig. 9). As mentioned before, a plain casing shoe inverted and threaded with left-hand threads may be used as an adapter. Another adapter in common use is a lead seal coupling (I and F, fig. 9), the top coupling, which has a left-hand thread, G, is fitted with a lead ring, F, which can be expanded by means of a swage or sealing iron tool to fit the outside casing D more closely. Into the lead seal coupling is screwed a short right and left hand thread nipple, E, on top of which is fitted a steel wash and pull ring, B. When the left-hand nipple E is backed off preparatory to pulling the top casing, this steel ring catches on the top coupling A of the wash pipe, and is pulled out.

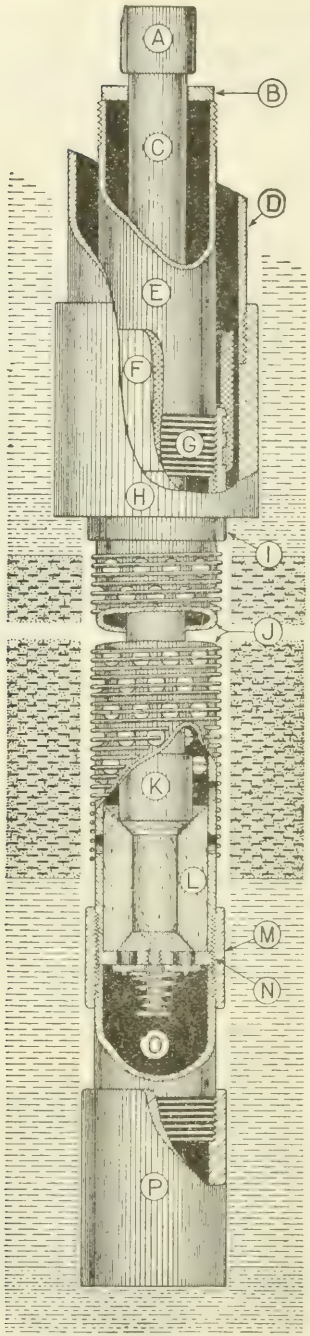
SPECIAL METHODS.

PURPOSE.

The wash ring D shown in figure 8 is of wood. Such a ring has often served the purpose well, but there have been a number of instances where it has failed. The water used in washing out the mud leaked by the wash ring to such an extent that not enough pressure could be maintained at the bottom of the hole to wash it so the pipe could be landed. Sometimes such a high pump pressure had to be used in washing that the wooden ring could not withstand the pressure and ultimately failed.

CANFIELD WASH RING AND PLUG.

In order to do away with this element of risk, Mr. Wallace Canfield has devised a wash ring made of babbitt. The assembled ring is shown in the left diagram of figure 10. For convenience in placing this wash ring, nipples are put in the wash pipe to bring it near the top of a joint of casing. A piece of babbitt, E, is molded to fit the casing in use. The upper part of the babbitt cylinder is turned off enough to permit $\frac{5}{8}$-inch hydraulic packing to be inserted between it and the casing. The lower part is drilled out in the center to fit the wash pipe coupling F. A nipple, D, is then screwed into this coupling and $\frac{1}{4}$-inch hydraulic packing is wrapped around the nipple for five or six inches. The babbitt cylinder E is then



A. WASH-PIPE COUPLING

B. STEEL RING

C. WASH PIPE

D. OUTSIDE CASING

E. BACK-OFF NIPPLE; RIGHT AND LEFT THREAD

F. LEAD SEAL

G. LEFT-HAND THREAD

H. CASING SHOE

I. LEAD-SEAL COUPLING ;RIGHT AND LEFT THREAD

J. SCREW PIPE

K. WASH-PIPE COUPLING

L. WASH PLUG, WOOD

M. COUPLING

N. BACK-PRESSURE VALVE

O. SHORT NIPPLE

P. CASING SHOE

FIGURE 9.—Method of setting screen pipe when it is desired to recover part of the oil string above the screen.

placed over the nipple D resting on the packing. The space around the outside of the cylinder is filled with packing, and a gland, C, of babbitt is set over this packing. A steel nut, B, is screwed onto the nipple D and drawn down tightly. In this manner the packing is compressed and a tight joint is made between the casing and the outside of the ring and also between the wash pipe and the inside of the wash ring.

The ring is made of babbitt in in order that it may have the required strength and also be soft enough to be worked past any rough or irregular places in the casing when it is removed. In order to do away with the swabbing effect of this ring when it is being pulled out, a short nipple, A, with $\frac{3}{4}$-inch holes drilled in it, is screwed into the coupling I. A coupling is also screwed onto this perforated nipple to facilitate screwing on the pulling string.

In the Canfield method, the back pressure valve (J, fig. 8), is also omitted. This valve has sometimes given trouble by getting stuck, the pump pressure being unable to loosen it again. The Canfield device has a wooden plug, G, turned up in a lathe to make a tight fit in the casing. A hole, with a diameter smaller than the wash pipe to be used, is bored in this plug. The plug is set on top of the rotary bit, a short nipple is fitted snugly into the hole in the plug, and the wash pipe is connected with the nipple by a reducer. This prevents the wash pipe from moving, thus making certain that the wash water

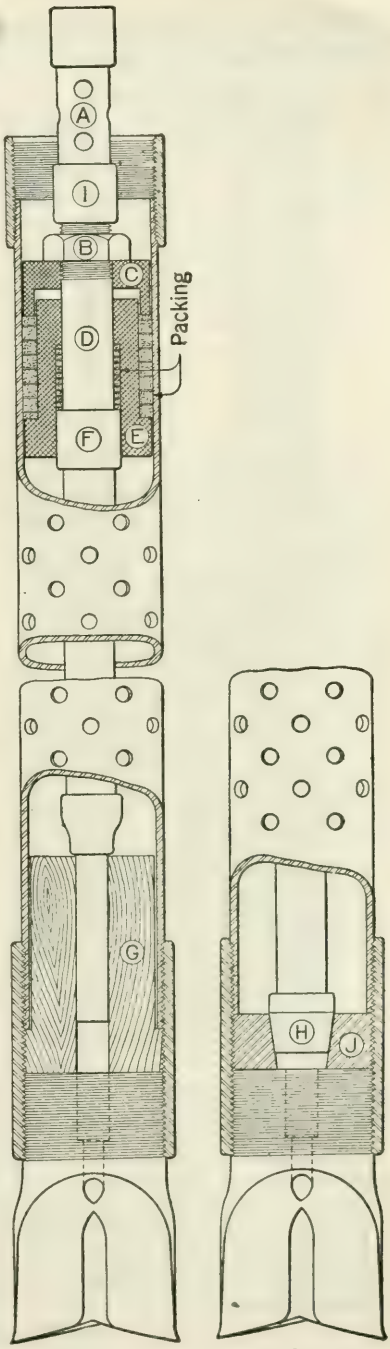


FIGURE 10.—Metal wash rings. *a*, Canfield babbitt wash ring; *b*, Canfield steel wash plug.

will always be directed where it is needed. When the wash pipe is pulled the short nipple will be withdrawn from the wooden plug.

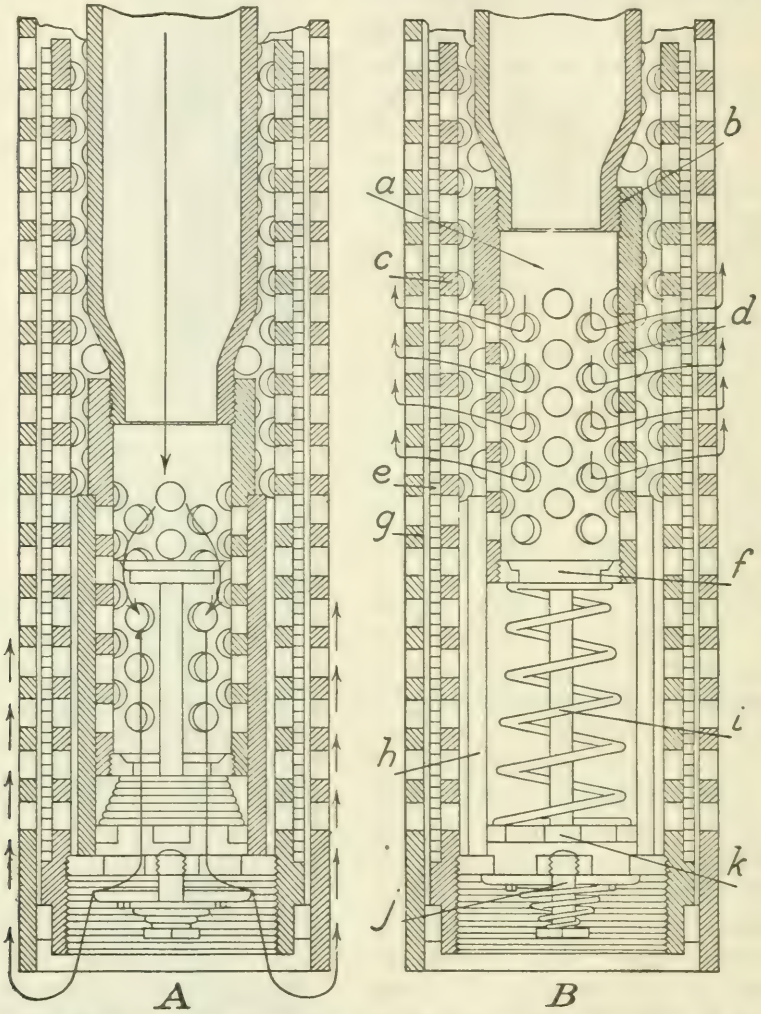


FIGURE 11.—Mack wash pipe, for washing out a hole when setting screen pipe. A, shows wash pipe with bottom open and sides closed, water flows through lower end and washes outside of screen; B, pipe with bottom closed and sides open, water washes screen from the inside and can be carried to any part of it with the full force of the pump. Arrows in view A indicate travel of water in both views. *a*, Wash pipe; *b*, connection to tubing; *c*, inside perforated pipe for screen; *d*, inside perforated pipe for wash pipe; *e*, screen wire; *f*, seat in bottom of wash pipe, which opens and closes; *g*, outside perforated jacket of screen; *h*, outside jacket of wash pipe; *i*, spring and stem controlling jacket of wash pipe; *j*, back pressure valve in screen; *k*, bottom seat of wash pipe.

CANFIELD METAL PLUG.

In some wells the gas pressure is great enough to unseat the wash pipe and start the fluid rushing through the bottom plug. In a short

time a channel is cut in the wood and when the wash pipe is again in place the fluid, instead of going out through the lower end of the casing, circulates around the bottom of the wash pipe and up the inside of the casing. To avoid this trouble, the Canfield method was improved by substituting for the bottom wooden plug G an iron ring two and one half or three inches thick, shown at J in the right diagram of figure 10. This ring is threaded and screwed into the coupling on top of the rotary bit. An annular, conical-shaped hole is drilled through the center of the ring, and the bottom coupling of the wash pipe H is turned to fit this opening. As the metal is much more resistant than wood, channeling with its detrimental results is avoided.

MACK METHOD OF SETTING SCREEN PIPE.

Mr. Mack has also devised an apparatus for washing out a well when setting the screen pipe. This device comprises a back pressure valve (fig. 11) so constructed that when the weight of the wash pipe is on the bottom, the wash water is forced to go out through the bottom of the pipe. When the screen pipe is set on bottom, the wash pipe is raised, and a spring in the back pressure valve forces the opening to close so that the water is directed laterally against the sides of the pipe and helps clear the screen of mud and sand.

"OPEN HOLE" THROUGH OIL STRATA.

Some oil sands are so hard and compact that they will stand up without the use of either screen or perforated pipe (fig. 12). This, fortunately, is the case in nearly all of the oil fields of the United States except those of California, Louisiana, and southern Texas, saving both time and money that would be otherwise spent in taking care of loose and running sands. When the oil sand is hard and compact, the oil string is usually carried as near the top of the oil sand as practicable and set on a firm shoulder. This shoulder should also make a tight joint to prevent encroaching waters reaching the oil sands[a] and to prevent cavings from above filling the hole. Later, if caving of the oil sand makes it difficult to keep the hole cleaned, a liner of some type can be set in with a string of tubing.

THE HARE OIL-WELL STRAINER.

In some wells where the placing of a screen or strainer at the time of drilling is unnecessary, detrimental conditions will develop later. Loose or floating sand will mingle with the oil and cut the pumps so badly that economical results can not be obtained. This

[a] Tough, F. B., Methods of shutting off water in oil and gas wells: Bureau of Mines, Bull. 163, 1918, p. 122.

condition is sometimes brought about after a well is shot, and seems to be a common occurrence when the oil is almost exhausted in a well.

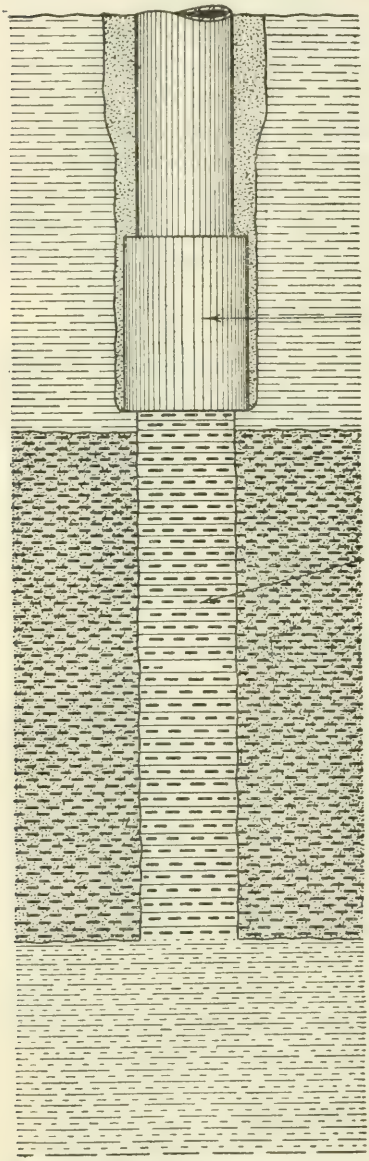


FIGURE 12.—Diagram showing condition where "open hole" is used through compact oil sand.

Mr. B. H. Hare devised a strainer, shown in Plate IV, *C* (p. 11), to prevent loose sand from entering the pump barrel. This device is placed just below the pump, so that all the fluid drawn from the well must enter through the wire gauze of the strainer. The mesh used is No. 80. This strainer is a somewhat recent invention, and its ultimate success has not been established. It is claimed to be giving good results in several wells in the Bradford field, Pennsylvania.

RECOMMENDATIONS.

1. Keep accurate well logs and casing records. The value of the ultimate results depends on the accuracy of these data.

2. Avoid perforating in the hole as much as possible. When this work can not be avoided, get the best machine and the best assistance available for the work. Before running the perforating machine into the well, test the machine on a length of casing identical with that to be perforated, not on any inferior piece of pipe which happens to be at hand.

3. Set either shop-perforated pipe or screen pipe wherever possible. The choice of kind of pipe should depend upon the nature of the producing formation.

4. Avoid any element of risk in choosing a method of setting in liners. The safest way is always the best. Also avoid moving the wire-wrapped type of screen, or any other type that has the screen-

ing apparatus on the outside of the casing, through formations unprotected by an outside string of casing. Such practice will more than likely disarrange the wire wrapping and even cause it to be torn off, thus rendering the screen valueless.

5. In wells where mud-laden fluid has been used and that do not have enough gas pressure to clean themselves, take every precaution to remove the mud from behind the screen pipe before it is finally set.

6. Use material in screens and strainers that will resist the corroding effect of underground waters, and use every precaution so to control the flow that the pipe will not be eroded by the cutting action of sand. This will prolong the life of the well.

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